NBS TECHNICAL NOTE 837

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Barrier Penetration Tests

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BARRIER PENETRATION TESTS

R. T. MOORE

ABSTRACT

Sixteen structural barrier panels were tested to determine their resistance to forcible penetration through the use of readily available tooling. Thirteen of these represented experimental techniques to reinforce an existing structural barrier of low penetration resistance; the other three were designs which would be most appropriate to consider as replacement barriers. Minimum man-passable sized openings were made in the barriers in working times which averaged 7.85 minutes and ranged from 1.52 to 25.56 minutes. One of the replacement and two of the reinforcing designs showed superior cost-effectiveness.

Seven woven, wire-mesh security fence specimens were also tested for their intrusion deterrence capability. The test results indicate that the deterrent influence of unelectrified fences of the type tested is largely psychological rather than physical. All of the specimens could be penetrated in 0.14 minutes or less.

Samples of the acoustical and vibrational data produced during the penetration tests add to the growing body of data which are expected to be useful in the design and selection of electronic intrusion alarm equipments.

Key Words: Barrier penetration; intrusion detection; intrusion resistance; physical security.

1. INTRODUCTION

The degree of protection that is afforded to computers, money or negotiable securities, weapons, classified materials, or other valuable items, is dependent upon the effectiveness of the physical security measures which are employed to safeguard them. Current physical security measures are usually based on the concept of employing one or more barriers, such as fencing, a strong room or a vault to enclose a protected area coupled with one or more electronic sensors which are intended to detect penetration of the barrier(s) or any intrusion into the protected area. Detection of barrier penetration or area intrusion causes an alarm and initiates some form of reaction on the part of guards, police or other forces.

The effectiveness of this approach is dependent on a number of factors including the reliability and detection capability of the electronic detection systems, the impregnability or penetration resistance of the physical barrier(s) and the response time of the security reaction forces. The most cost-effective physical security system must take into account the interrelationships between these factors. A "perfect" electronic detection system might be of little value in safeguarding a volume whose barriers could be penetrated in five minutes if the intrusion alarm reaction time were ten minutes. Given the same ten minute reaction time, a barrier with fifteen minutes penetration resistance might be ineffectual if the electronic intrusion detection alarm was not activated until the final moment of breakthrough.

During the latter part of 1971 a number of tests were conducted to develop information useful in assessing the penetration resistance of conventional structural barriers. Attacks were made using readily available portable tools and penetration was assumed to have been accomplished when an opening had been made with a minimum area of 96 square inches and having one dimension of at least six inches. The time required to penetrate was recorded together with the acoustic, ultrasonic and vibrational disturbances produced by the attack. These tests showed that many of the structural barriers which had a superficial appearance of durability could in fact be breached quite rapidly. Of the ten structural barriers tested, six were penetrated in less than one minute and only two resisted attack for more than four minutes. A 12-inch thick brick wall required only nine minutes and an eight-inch thick reinforced concrete floor would have required an estimated 41 minutes to penetrate based on extrapolation of measured time for partial penetration.

These test results indicate that there may be many circumstances where existing barriers might be reinforced in order to favorably balance the time required for penetration against the intrusion reaction time of security forces. The possible improvements which might be realized through the use of unconventional combinations of materials to reinforce an existing barrier of conventional design were of particular interest.

A number of candidate experimental designs were prepared and submitted to interested members of the security community for review and comment. From this, a plan evolved to construct sixteen structural barriers and a woven-mesh fenced enclosure for testing. Thirteen of the structural barriers reflected experimental concepts of reinforcing an existing barrier of low penetration resistance. The remaining three represented possible designs for initial construction of barriers intended for use in applications involving a moderate level of security.

The structural barriers were constructed in the form of four unroofed boxes using a different construction design selected from the list for each wall. Each barrier panel was eight feet long and six feet high so as to provide enough area for multiple attacks when alternative tooling was indicated. They were constructed on an asphalt parking area near the south edge of the National Bureau of Standards facility. The masonry work was completed during the fall of 1972, but the concrete and ferrocement construction was delayed by winter weather and was not completed until April 1973. Testing was begun after a minimum curing time of 28 days.

The woven mesh fencing was constructed on a grassy area adjacent to the barrier test site in the form of a 20' X 100' enclosure with two double-hung gates. One-half of the enclosure was constructed from U. S. gauge materials (two sizes) and the other half employed metric gauge materials (five sizes). Within the enclosure, a short section of concertina wire barrier was also set up for test. Construction of the fencing was completed by mid-June 1973 and the testing followed immediately thereafter.

2. TEST OBJECTIVES

The objectives of the tests on the structural and fencing barriers were to develop estimates of the relative cost-effectiveness of alternative materials and construction techniques; to determine the times required to make minimum size man-passable penetration openings, and to collect samples of the acoustic, ultrasonic and vibrational disturbances produced by the various attacks.

The relative cost-effectiveness of a barrier can be evaluated in terms of the amount of resistance to penetration which can be obtained versus the cost required to obtain that resistance. This can be expressed as the relation $R = W/C$, where R is the relative cost-effectiveness, W is the minimum working time required to make a penetration of the required size and C is the cost of the barrier per unit area.

Construction costs are a function of labor costs and material costs which may both vary widely with time and geographic location. They are also influenced by the economies of scale; the cost per square foot of a 6' X 8' test panel may be considerably different than for an enclosure with 10,000 square feet of barrier surface area. For these reasons, it is believed that some means of normalizing the cost factor should be employed in order to develop a more generally applicable expression of relative cost-effectiveness. This has been done by using the engineering cost estimates for each of the panels. In the case of the three panels which reflect initial construction, the total cost was used. The lowest per-square-foot cost estimate was assigned a value of unity and the others were scaled up accordingly.

The relative cost-effectiveness of the reinforcing concepts employed in eleven of the barrier test panels is conceptually similar and may be expressed as: $Rr = (W-X)/Cr$, where X is the estimated or measured time to penetrate the barrier without the added reinforcing (never more than two minutes) and Cr is the estimated cost of reinforcing which is normalized against the other candidate cost estimates as previously described.

It is important to recognize that the values of R or Rr have limited meaning except when considered in terms of a required value of W. Two barriers could have equal values of R but one could exhibit W many times larger than the other. The factor W is the actual working time required to make a penetration of the stipulated area. Working time is considered that amount of time during which the attack tooling is being actively employed. It does not include intervals required for changing tools, selecting the next place to drill a hole, changing to a fresh operator when the first attacker becomes fatigued, or similar

interruptions to an attack which would be necessary with even a skilled team of determined attackers. Elapsed time was also recorded to take into account these additional factors. A barrier is considered to have been penetrated when an opening had been made which is large enough for a small man to wriggle through. It is generally accepted that an opening having an area of 96 square inches with one dimension of at least 6" will meet this criterion. In these tests, attack areas were marked out on the barriers in the form of either an 8" X 12" rectangle or an 11.1" diameter circle as appropriate to the attack tooling which was employed. In those instances where the attack produced an opening larger than, or significantly different from these sizes, its dimensions are reported.

3. TEST IDENTIFICATION

Each proposed structural barrier target area for a penetration attack was assigned an alphanumeric identifier which was painted on the external surface of the selected barrier adjacent to the perimeter of the planned opening. It is used to label test data from each attack and is especially helpful in identifying photographic records. The identifier consists of a number-letter sequence in which the first number indicates the barrier to be attacked. The following letter indicates the area of the attack and the general nature of the initial tooling used on that area.

Letters designating initial tooling were selected from the following list:

A. Sledgehammer
B. Rotohammer
C. Diamond Drill
D. Burning Bar
E. Linear-Shaped Charge
F. Demolition Saw
G. Pneumatic Jackhammer
H. Rock Melter
J. Water Jet
K. Battering Ram
M. Gasoline-Powered Rotary Saw
N. Electric-Powered Rotary Saw
P. Cutting Torch
Q. Electric Drill
R. Saber Saw
S. Brace and Bit

T. Bolt Cutters

U. Cutting Maul

In the case of the fencing materials, identifiers F1 through F7 were used to cover the seven types of material tested.

4. INSTRUMENTATION

Acoustic and ultrasonic disturbances produced by the various attacks were observed using a 1/4" microphone having a nominally flat frequency response to above 50 kHz. This was mounted on a small tripod and together with its preamplifier and power supply was positioned 12' from the attack location and in such a way as to try to minimize the pickup of signals directly reflected from adjacent barrier panels. Since it is unlikely that microphone positioning was completely effective in eliminating the effects of reflected signals, no attempt has been made to correct the observed data or compensate for minor deviations from the nominally flat frequency response of the microphone. The data are presented as spectrum analyzer outputs and are expressed as dB above a zero level of .0002 dynes per square centimeter. They should be considered as representative values only.

Vibrational disturbances were picked up by piezoelectric transducers which were mounted on the interior surface of each barrier at the longitudinal center and approximately 8" below the top edge. They were at a distance of approximately 42" (plus the thickness of the barrier) from the center of each attack point. The frequency response of the transducers extended to over 100 kHz. Their associated charge amplifiers were located within a portable protective enclosure and were coupled by a low impedance transmission line to the data recording position. The recorded vibrational spectra are expressed as peak g values. These, like the acoustical and ultrasonic disturbances, should be considered only as representative values as the natural resonances of a panel secured on only three sides could differ considerably from one secured on all four sides as in a room or vault.

The transmission lines from the charge amplifiers and microphone preamplifier were each terminated at a selector switch box arranged so that either one could be selected as the input to a real-time spectrum analyzer. The output of the spectrum analyzer was displayed on a storage tube oscilloscope and photographs were taken of samples of the spectra of the disturbances. The data recording instrumentation was located in a garage area adjacent to the barriers.

The spectrum analyzer was operated with a sweep width of 50 kHz, a sweep rate of 5 kHz per cm (on the display), a sweep speed of 30 ms per cm and a bandwidth of 500 Hz. The vertical axis of the display showed the spectral amplitude in a logarithmic mode with sensitivity of 10 dB per cm and covered a dynamic range of 60 dB. The type of spectrum analyzer used does not have memory; that is, it displays those spectral components of the signal which are within its passband at the "instantaneous" center frequency of the sweeping passband. A single sweep provides a reasonably good representation of continuous signals such as from a motor-driven tool or a cutting torch, but on intermittent signals, such as hammer blows, many sweeps may be required to develop an estimate of their spectrum over the full 50 kHz sweep width. This is because on one hammer blow the passband of the analyzer may be sweeping past the 5 kHz region and on the next it may be sweeping past the 35 kHz region. Under circumstances such as these, multiple sweeps were collected on the storage tube oscilloscope prior to photographing them whenever the attack duration was long enough for this to be feasible.

On most of the tests, sound pressure levels (SPL) were also observed at distances of 8' to 12' from the attack using one of three different handheld sound pressure level meters. One of these was equipped with a 1/2" microphone and was operated in the linear mode (no frequency weighting filters). Data from this are reported as dB. The other two meters were equipped with one-inch microphones and a C weighting network. Data from these are reported as dB·C. In all cases, the distance from the attack point to the observer is reported.

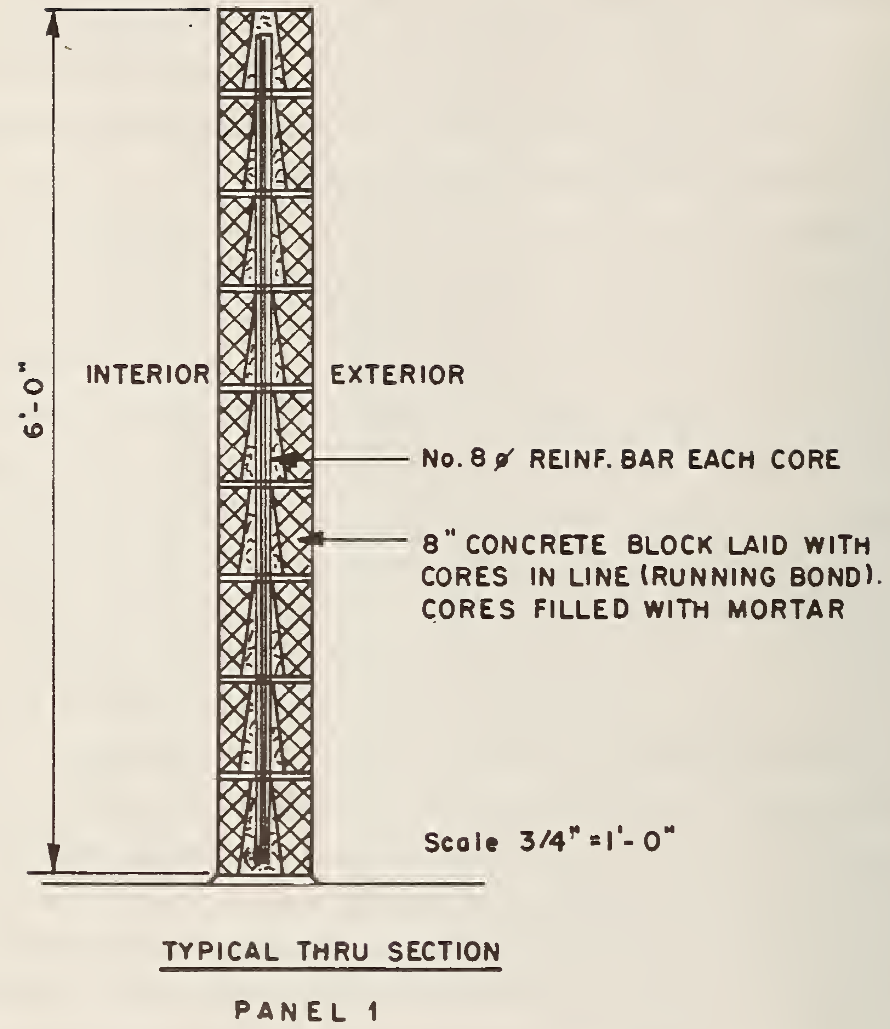


Figure 1. Construction of Panel 1

Timing information on the penetration tests was obtained using two manually-controlled clocks. The elapsed time was determined from a large-face, self-starting electric clock located within the field of view of cameras covering the attack. It was equipped with a switch in the power cord and this was turned on at the beginning and off at the end of each attack. Prior to each attack, the hands would be set to an integral hour plus zero minutes and zero seconds. The accrued minutes and seconds at the end of the attack then indicated the elapsed time directly. Working time was accumulated on a restartable, handheld stopwatch. The uncertainty in the accumulated working time values is believed to be on the order of one second per increment of working time, and probably does not exceed five percent of the total reported even in the case of the numerous increments developed in a few of the attacks.

5. RESULTS OF TESTS ON THE BARRIER PANELS

Test results are reported sequentially by panel number although this does not correspond to the chronological sequence of attacks which was adjusted to accommodate a number of factors, such as weather, photographic coverage and the minimization of instrumentation relocations.

5.1 Panel 1

The construction of Panel 1 is shown in figure 1. It is unlikely that reinforcing rods and mortar fill could be added to an existing hollow core concrete block barrier, and, while such a structure could be built either inside or outside of an existing barrier, it is more likely to occur as initial construction.

5.1.1 Test 1A

A ten-pound sledgehammer was used to attack the target area. The initial breakthrough occurred after 54 blows which required 1.31 minutes working time. After another 47 blows and 1.12 minutes, the opening had been enlarged to approximately 12" X 15". The hammering produced SPL readings of 87 to 88 dBC as observed at a distance of 12 feet. A multiple sweep recording of the vibrational disturbances is shown in figure 2. A single reinforcing rod bisected the opening and required two cuts with an oxygen acetylene torch to remove it. The torch was operated at 20 p.s.i. oxygen pressure and 7 p.s.i. acetylene pressure

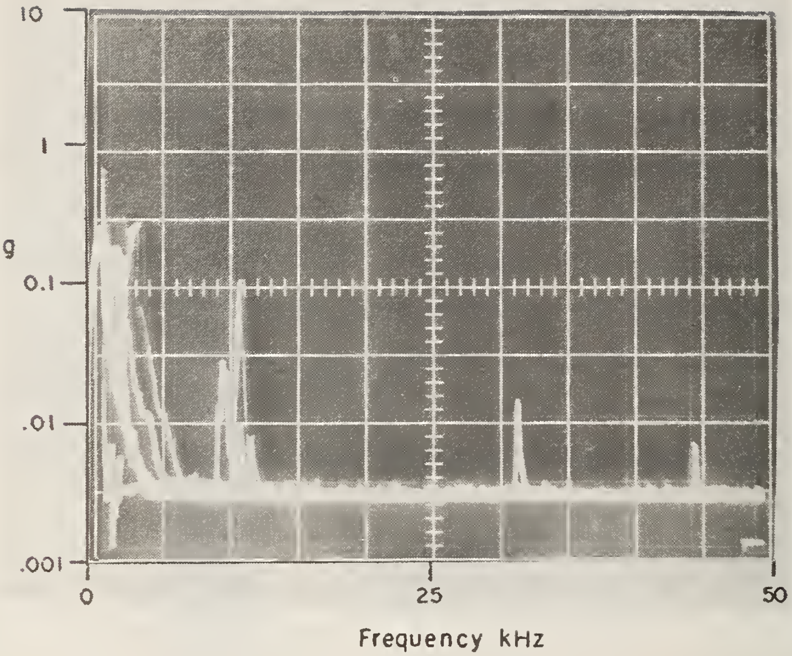


Figure 2. Multiple Sweep Recording of Vibrational Disturbances; Test 1A

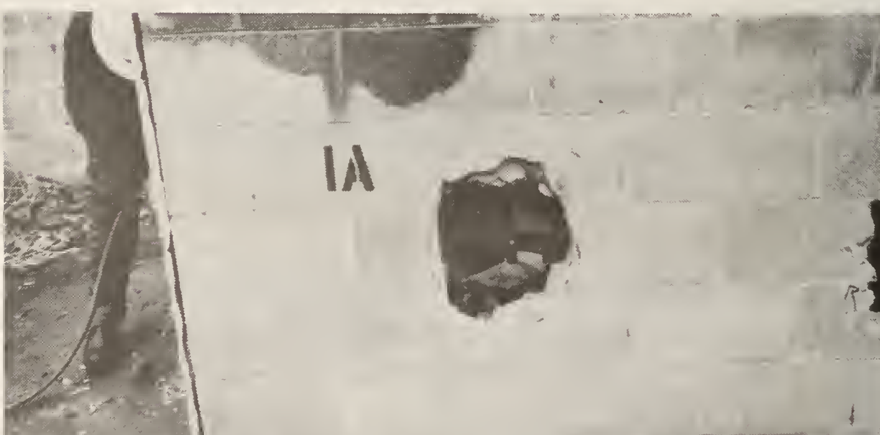


Figure 3. Opening Produced by Test 1A

and a number 5 cutting tip was employed. (Unless otherwise noted, these same gas pressures and tip size were used for all torch cuts in the test series.) The two cuts were made by a relatively inexperienced operator and required 1.41 minutes yielding a total working time of 3.84 minutes and elapsed time of 5.03 minutes for the penetration shown in figure 3. A more experienced torch operator then demonstrated that the section of reinforcing bar removed from the opening could be cut in only 19 seconds. It appears reasonable to expect that this operator could have completed the penetration in a total working time of only 3.06 minutes.

5.1.2 Test 1K

Using a rotohammer with 3/4-inch drill, a circular pattern of holes was made at the target location. Five equispaced holes were to be drilled on the circumference of a 12-1/4-inch diameter circle to a depth of 5 inches. One of the holes was inadvertently drilled completely through. At a sixth hole at the center of the circle, a reinforcing bar was encountered at a depth of about 3-1/2 inches. Then five more holes were drilled to a depth of 3 inches at points along the circumference of the circle, midway between each of the 5-inch deep holes, and three additional holes were drilled equispaced on the circumference of a smaller 5-3/4-inch diameter concentric circle. One of these latter holes also encountered a reinforcing bar. Vibrational disturbances produced by the drilling are shown in figure 4. When any reinforcing bar was encountered, drilling on that hole was terminated and the hole was marked so that subsequent spalling operations could readily bypass such holes. The drilling required 3.60 minutes working time for the nominal 54 inches giving an average rate of 4.1 seconds per inch.

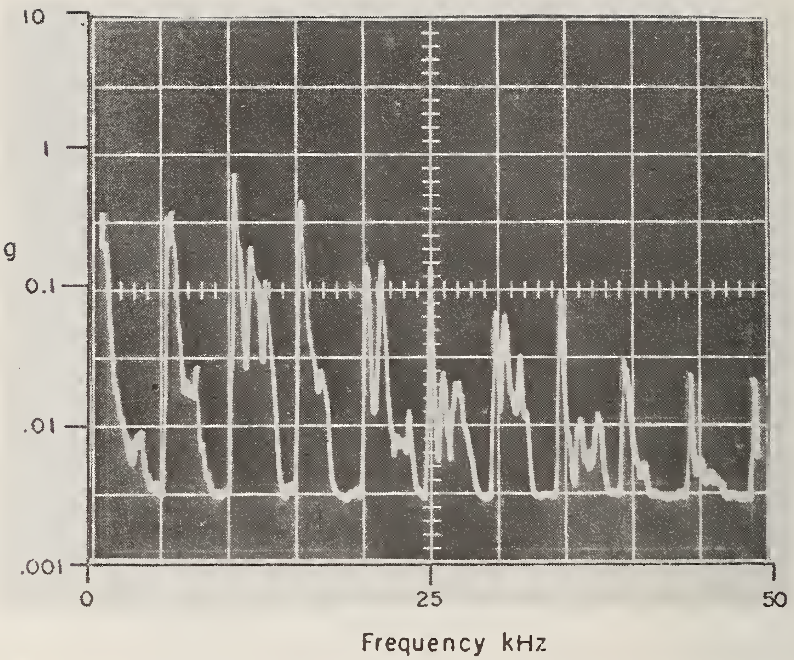


Figure 4. Test 1K. Vibration from Drilling

Next, using a 10-pound sledgehammer and a variety of steel punches, material was spalled from the bottoms of the unmarked 5-inch deep holes on the interior of the panel. Four of these holes were spalled out with 41 blows of the sledgehammer. The fifth hole was more resistant and when the punch bent attention was shifted to the intermediate 3-inch deep holes. These also resisted spalling and two more punches were bent (see figure 5) so it was decided to remove the punches and drill an inch deeper on the unmarked 3-inch holes. These spalling activities had consumed an additional 1.89 minutes of working time. The extra drilling required 0.92 minute. The spalling was then resumed and proceeded fairly rapidly, being completed in another 1.05 minutes and producing vibrational disturbances as shown in figure 6. Typical SPL readings of 82 to 87 dBC were observed at a distance of 12 feet.

Figure 5. Spalling from Hole Pattern;
Test 1K

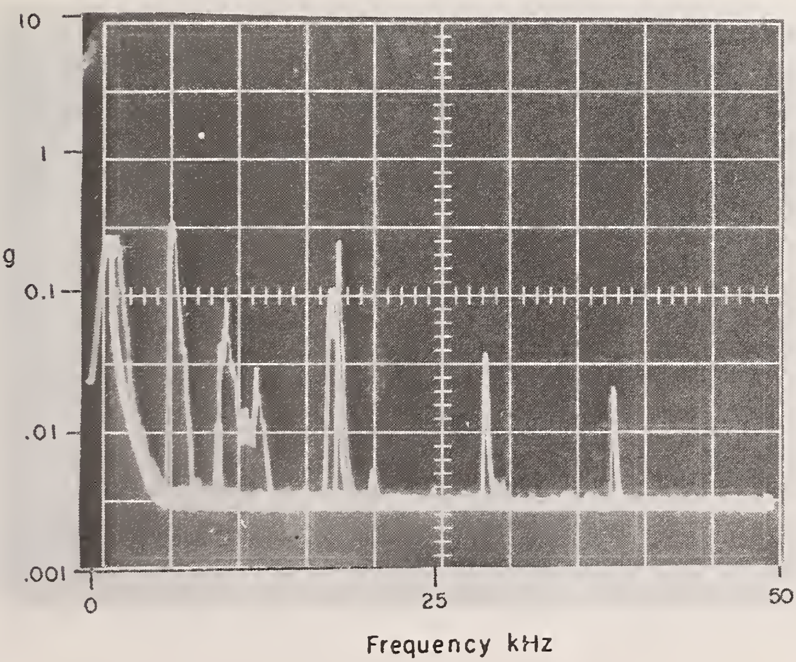
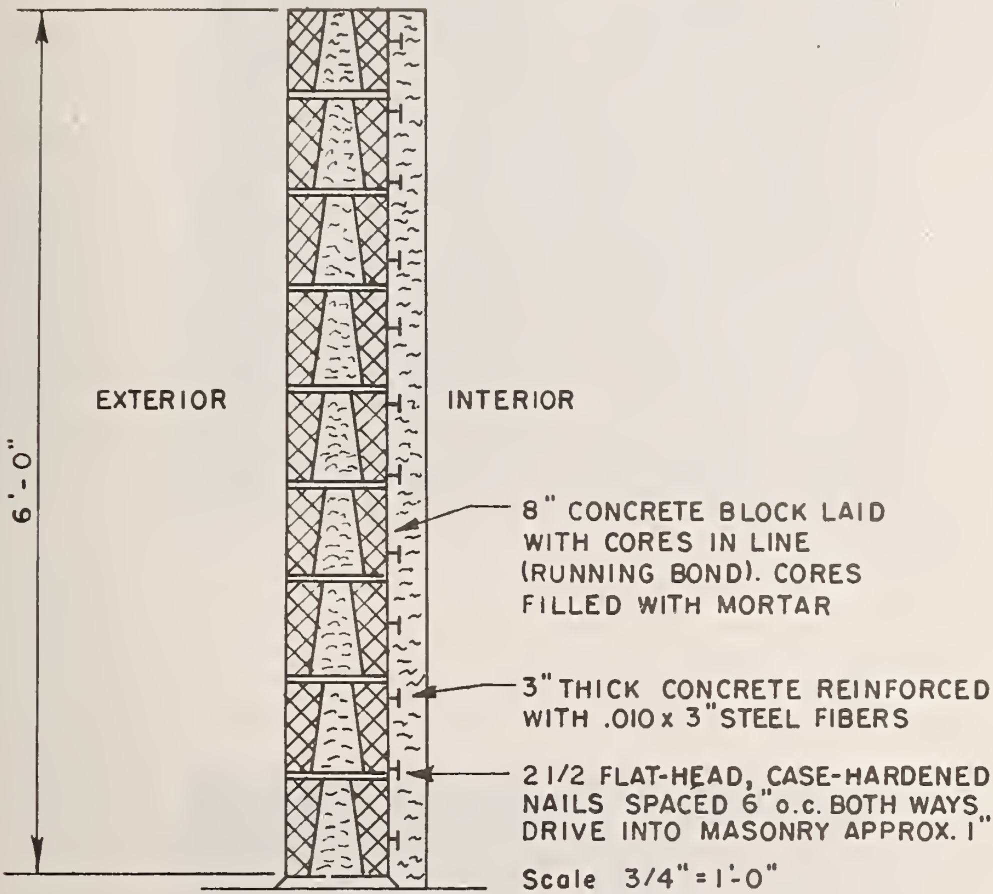


Figure 6. Vibrational Disturbances from Spalling;
Test 1K.

At this point the total accumulated working time was 7.55 minutes and the interior spalling had reduced the thickness of the panel to about 4 inches over nearly all of the target area. A 50-pound battering ram was then tried against this remaining thickness. It was handheld by two operators who swung it against the wall by it's steel handles. This proved to be quite unsatisfactory. The impact shocks that were transmitted back through the handles were greater than the operators could tolerate, and after only five blows the ram was abandoned in favor of the 10-pound sledgehammer which was effective in clearing out the opening with 55 blows delivered in 1.28 minutes. Then the oxygen acetylene torch was employed for 1.25 minutes to cut out the reinforcing bar (see fig. 7). The total working time was 10.22 minutes and elapsed time was 12.42 minutes.

Figure 7. Cutting Reinforcing Rod in Test 1K



TYPICAL THRU SECTION

PANEL 2

Figure 8. Construction of Panel 2

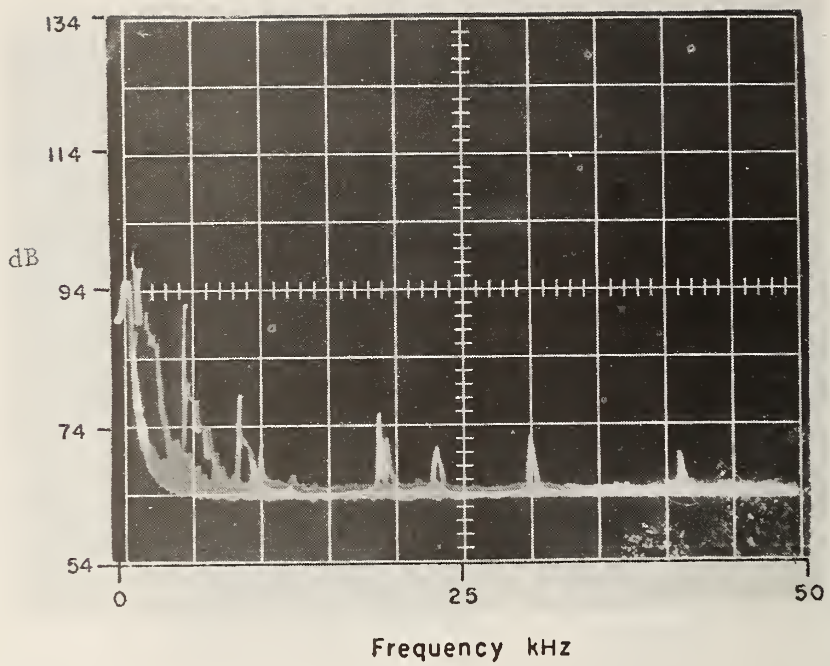


Figure 9. Multiple Sweep Spectra of Acoustical Disturbances; Test 2A

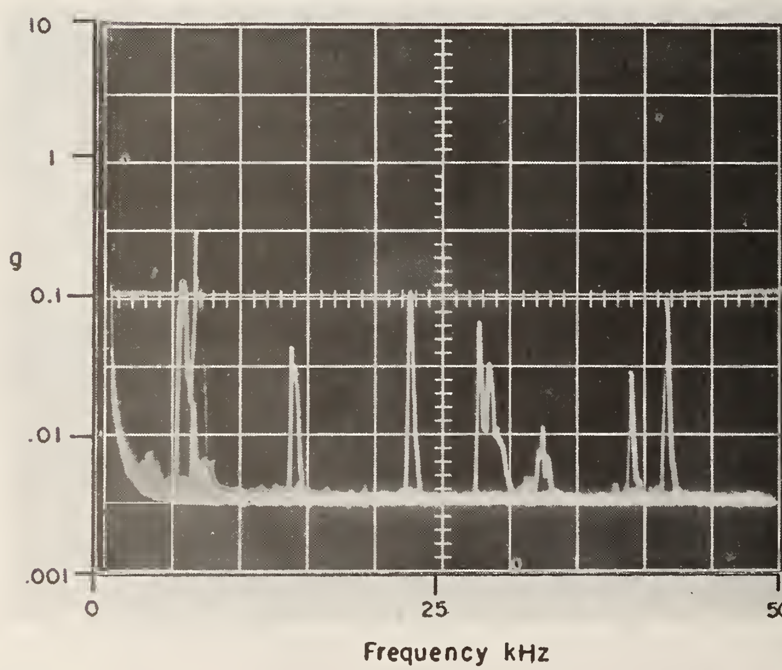


Figure 10. Multiple Sweep Spectra of Vibrational Disturbances; Test 2A

5.2 Panel 2

The construction of Panel 2 is shown in figure 8. Here, a mortar-filled concrete block wall has been reinforced with a 3-inch thick lining of fibrous concrete which was bonded to the block by 2-1/2-inch case-hardened nails which were driven one inch into the block prior to casting the liner.

Prior experience had indicated that a mortar-filled 8-inch thick block wall could be penetrated in less than two minutes[1/] and that a 4-inch thick reinforced fibrous concrete barrier could be penetrated in less than 10 minutes[2/]. In combination, however, they proved to be unexpectedly resistant and penetration required more than twice the working time necessary for any of the other panels in this series.

5.2.1 Test 2A

The attack was initiated with a 10-pound sledgehammer. Typical multiple sweep spectra of the acoustical disturbances are shown in figure 9 and the vibrational disturbances in figure 10. After 324 blows, which required 7.80 minutes of working time and 20 minutes elapsed time, an opening had been produced which had dimensions of approximately 15" X 14" X 5" deep. The average SPL during this portion of the attack was approximately 86 to 90 dB as observed at a distance of 12 feet.

It had been noted that the sledgehammer seemed to be somewhat ineffective in removing the mortar filling which appeared to absorb the energy of the hammer blows with minimal surface spalling so a 6-pound cutting maul was brought into play. The cutting edge of this tool appeared to remove more mortar per blow than the sledgehammer. It produced quite similar vibration disturbances as shown in figure 11.

1/ NBSIR 73-223, Penetration Tests on JSIIDS Barriers, June 4, 1973, R. T. Moore.

2/ NBSIR 73-101, Penetration Resistance Tests of Reinforced Concrete Barriers, December 1972, R. T. Moore.

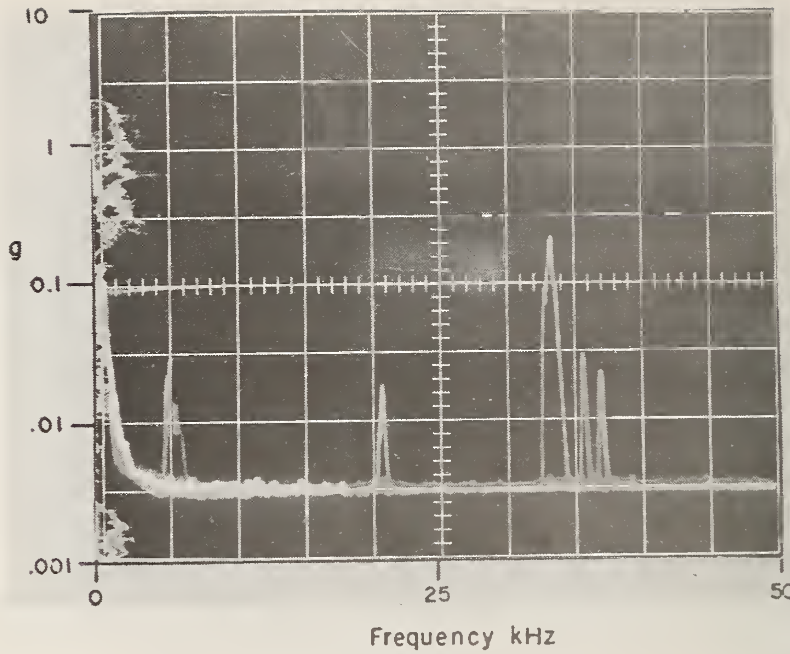


Figure 11. Vibrational Disturbances Using a 6-pound Cutting Maul; Test 2A

After 100 blows, the depth of the opening was increased to 7-1/2 inches. These produced SPL readings of 80 to 85 dB at a distance of 12 feet and increased the accumulated working time to 10.09 minutes and the elapsed time to 26.05 minutes. Then the sledgehammer attack was resumed in order to enlarge the area of the opening slightly to permit better hammer access to the fibrous concrete lining. Forty additional blows enlarged the surface of the opening to approximately 17" X 19", and, after 20 more blows, the liner was reached and immediately the SPL readings increased to 96 to 98 dB at 12 feet. After another 81 blows, an initial interior spalling crack appeared as shown in figure 12. Four more blows and the initial breakthrough occurred. This was about three inches in diameter and approximately the size of the sledgehammer head. It may be seen in figure 13. On the interior, the spalled surface was irregular in shape and approximately 13" X 17". This breakthrough required 469 blows from the sledgehammer and 100 blows from the 6-pound cutting maul which were delivered in 13.74 minutes working time and 36.42 minutes elapsed time.

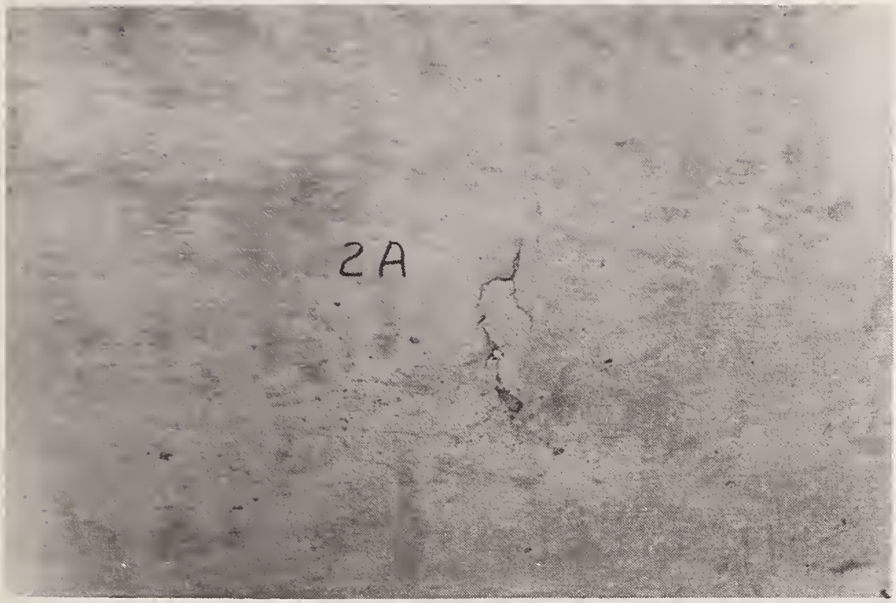


Figure 12. Initial Interior Crack in Fibrous Concrete ; Test 2A

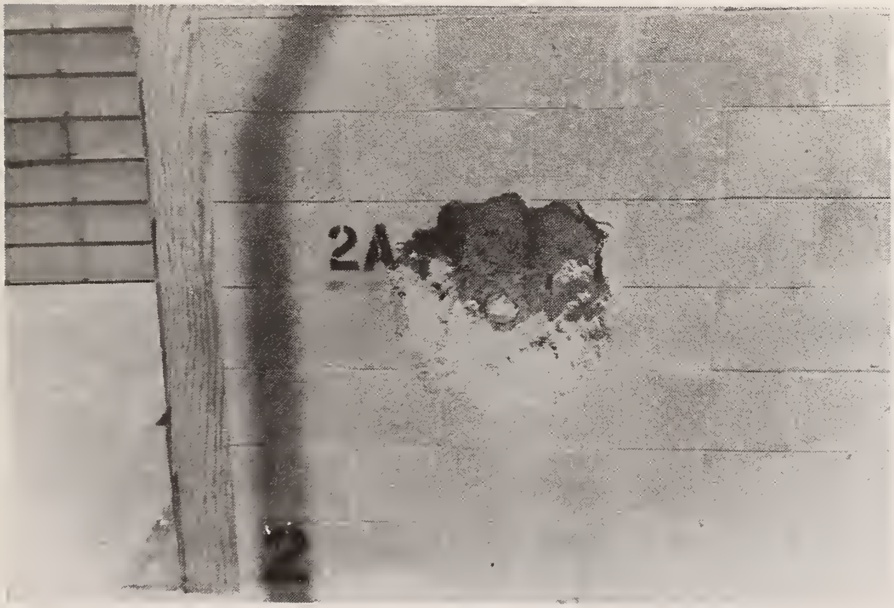


Figure 13. Initial 3" Diameter Breakthrough Resulting from Sledgehammer and 6" Cutting Maul Attack; Test 2A

Figure 14. Attack 2A. Exterior, Attack in Process

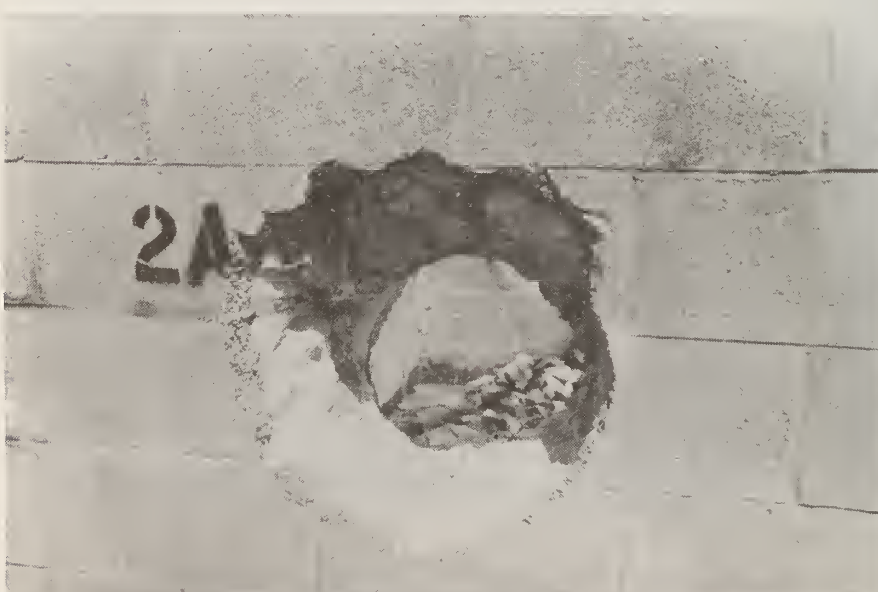


Figure 15. Attack 2A. Exterior View, Final Opening

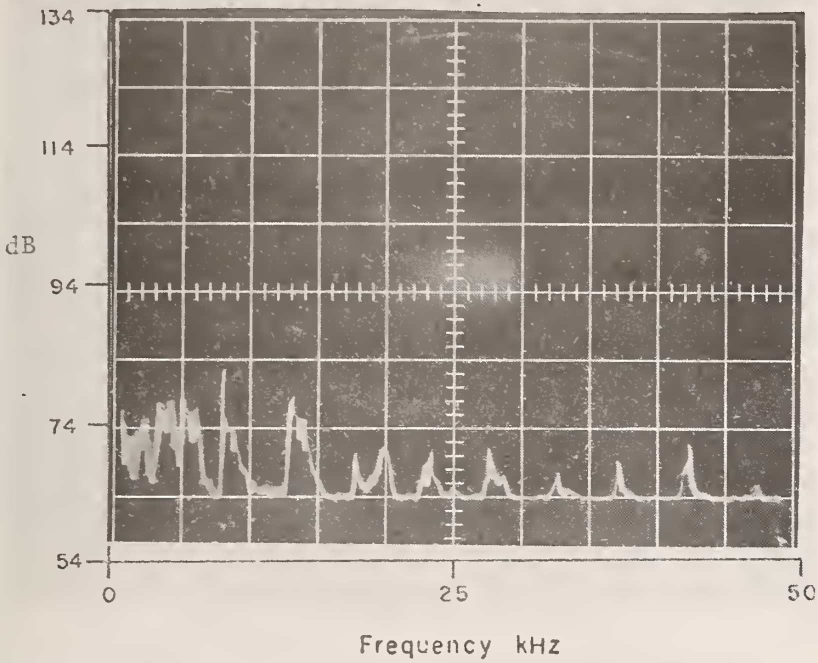


Figure 16. Acoustical Disturbances Resulting from Drilling; Test 2B

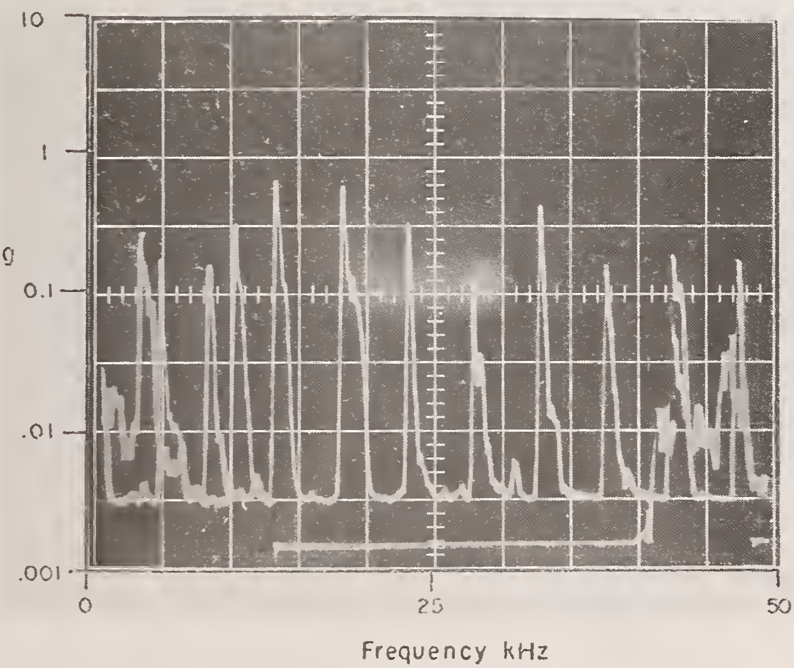


Figure 17. Vibrational Disturbances Resulting from Drilling; Test 2B

Thereafter, the opening was enlarged by using the cutting maul and sledgehammer in alternating series of blows as in figure 14. The final 96 square inch opening was nearly circular in shape and appears in figure 15. It required 725 blows with the 10-pound sledgehammer and 300 blows with the 6-pound cutting maul. The total working time was 25.56 minutes giving an average time of 1.575 seconds per blow. The elapsed time was 58.75 minutes. The penetration was accomplished by a fresh two-man team of Marines who were in excellent physical condition and who were motivated to try to better penetration times which had been recorded in prior tests involving Army and Navy personnel. It is believed that a five-man team of intruders would be necessary in order to reduce the elapsed time to a value just slightly greater than the working time for an attack of this type and duration.

5.2.2 Test 2B

The plan for attack 2B was to attempt to spall off the fibrous concrete liner under the target area and then break through the concrete block. Eight holes, 3/4" in diameter, were drilled with the rotohammer equally spaced around the circumference of a 12"-diameter circle and a ninth hole was drilled in the center. All were drilled to a depth of 8". This required a working time of 3.77 minutes and 5.62 minutes of elapsed time. The average drilling rate was 3.95 seconds per inch. Samples of the acoustical, figure 16, and vibrational, figure 17, disturbances are typical.

Next, a 3/4" diameter bull point punch was inserted in the center hole. When 40 blows on this with a 10-pound sledgehammer bent the punch and failed to spall through the liner, it was decided to try to spall in easier stages and alternate holes around the periphery of the attack circle were drilled 1-1/2" deeper to a point which was calculated to be halfway through the liner. These four holes were then quickly spalled out with the punch using a total of only six blows from the sledgehammer. At this point the working time was 6.40 minutes and elapsed time was 8.42 minutes.

A 12" cut nail (1/2" square) was then used as a punch in one of the 8" deep holes and it was bent after only five blows. The bent punch in the center hole was still jammed in place, so it was decided to free it by drilling next to it and, in so doing, enlarge the hole to accept a larger punch. A 1-1/4" taper punch was inserted in the enlarged center hole, and, after 55 more blows with the 10-pound sledgehammer, the hole was spalled through. An interior view of the spalling is shown in figure 18. Typical spectral of the acoustic disturbances are shown in figure 19, and the vibration disturbances in figure 20, both of which are multiple sweep exposures. At this point, the test was suspended to permit acquisition of more punches. The accumulated working time was 7.68 minutes and the elapsed time 10.53 minutes.

Figure 18. Spalling Produced by Punch in Center Hole; Test 2B

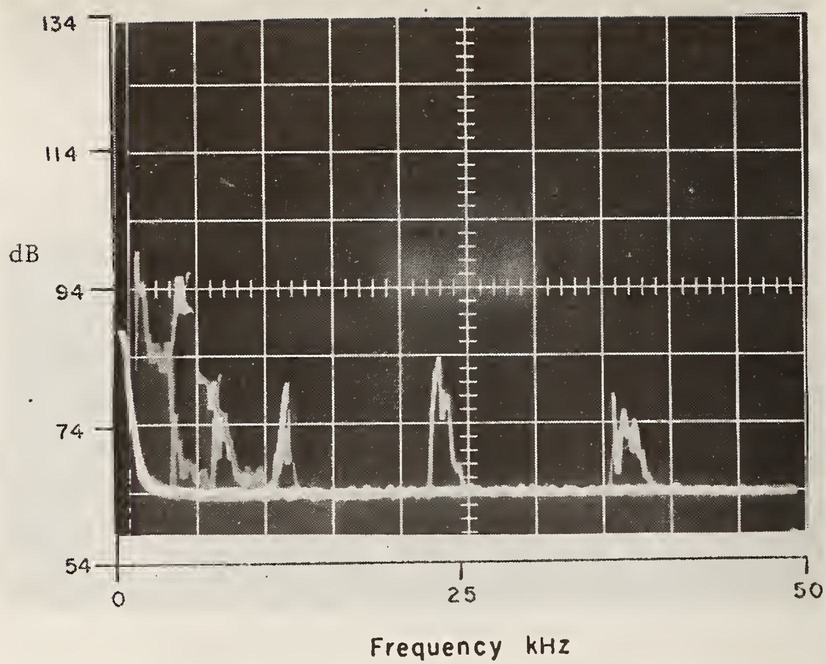


Figure 19. Multiple Sweep, Typical Spectra of Acoustical Disturbances; Test 2B

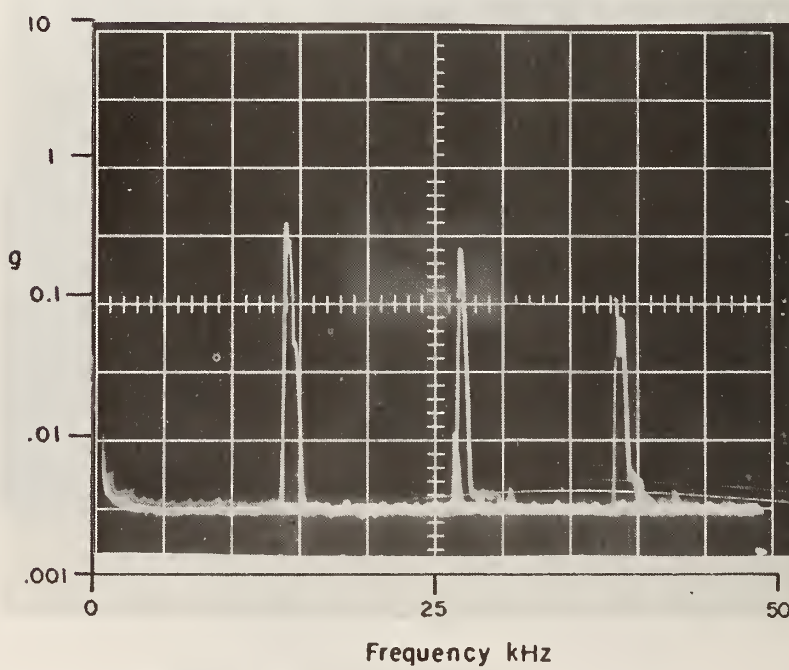


Figure 20. Multiple Sweep, Typical Spectra of Vibrational Disturbances; Test 2B

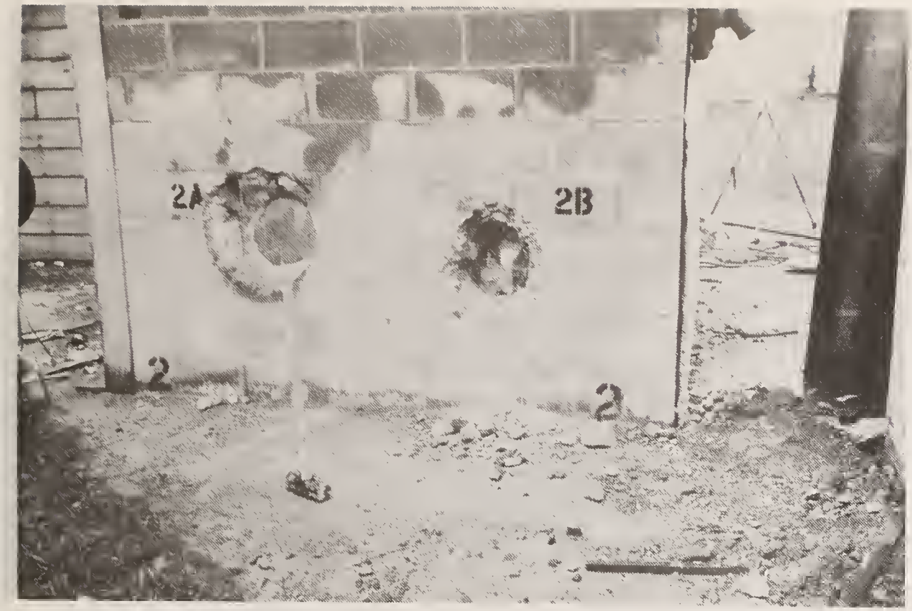


Figure 21. Breakthrough Hole after Numerous Blows; Test 2B

Figure 22. Enlarged Opening with 26-lb. Bar; Test 2B

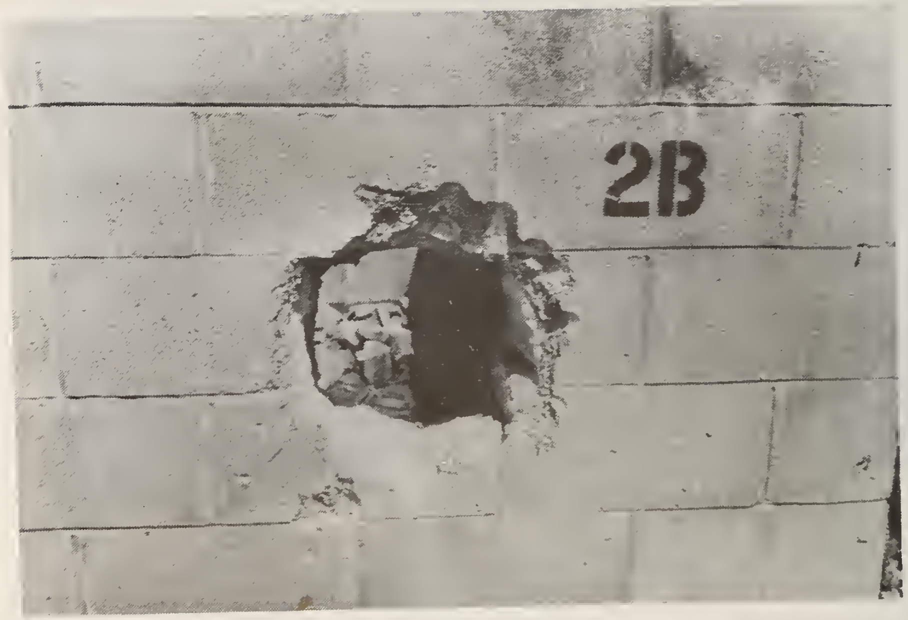
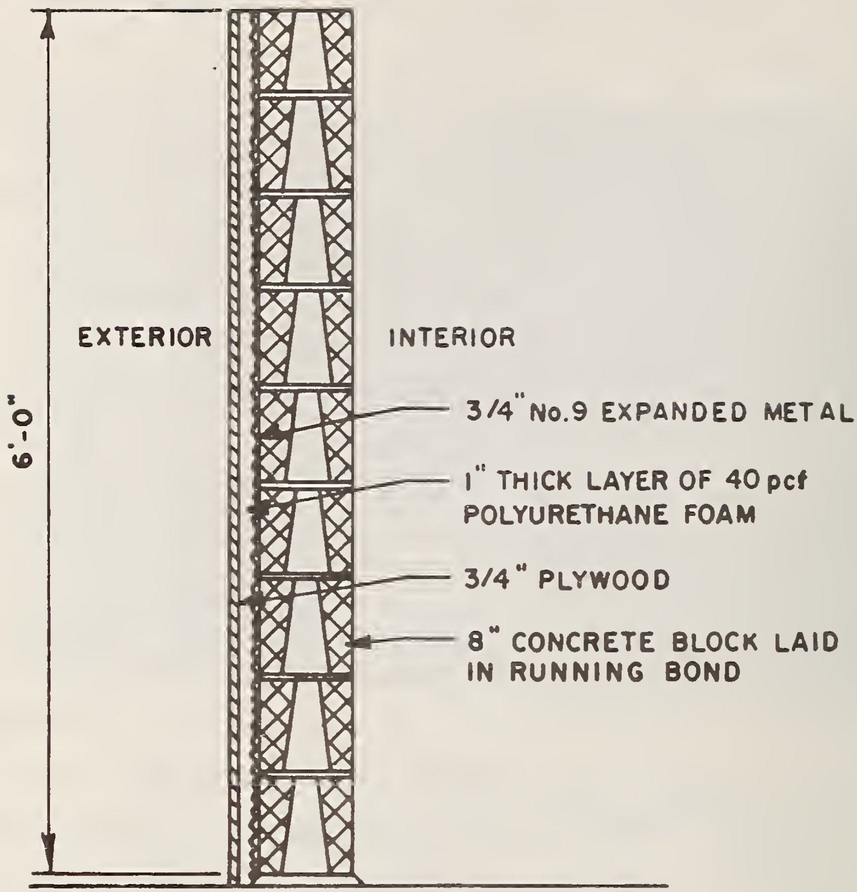


Figure 23. Exterior View, Final Enlarged Breakthrough; Test 2B

The test was resumed after more punches had been obtained, and spalling began on the four intermediate holes which were 8" deep. These were cleared with 29 blows of the 10-pound sledgehammer which took 0.59 minute working time. Then a direct attack was begun on the remaining central section of the target area using the 10-pound sledgehammer. After 120 blows, only the outer shell of the concrete block had been cleared so attack tooling was shifted to a 26-pound wrecking bar using the chisel pointed end. After a total of 140 blows with the bar and at an accumulated working time of 13.97 minutes, a 2" X 4" breakbrough hole was developed as shown in figure 21. This was enlarged with another 61 blows with the bar, figure 22, and then the 1-1/4" tapered punch was used in each of the peripheral holes to spall the remaining material into the central opening. Four of the holes were spalled out in 210 blows with the 10-pound sledgehammer, then the 26-pound bar was used for another 80 blows. Then three more peripheral holes were spalled into the central opening using the 1-1/4" diameter taper punch and 19 sledgehammer blows. A final 20 blows with the 10-pound sledgehammer and 123 blows with the 26-pound bar brought the opening to the required size as shown in figure 23. The total working time was 26.55 minutes and the elapsed time was 33.5 minutes. In addition to the drilling operations, it required 484 blows with the 10-pound sledgehammer and 424 blows with the 26-pound bar. A three-man attack team was used until the time that the test was suspended and a six-man team worked when the test was resumed. This larger attack team size accounts for the more favorable ratio of working-to-elapsed time as compared with test 2A.



PANEL 3

Figure 24. Construction of Panel 3

Figure 25. Opening Produced by 6-lb. Chopping Maul; Test 3A

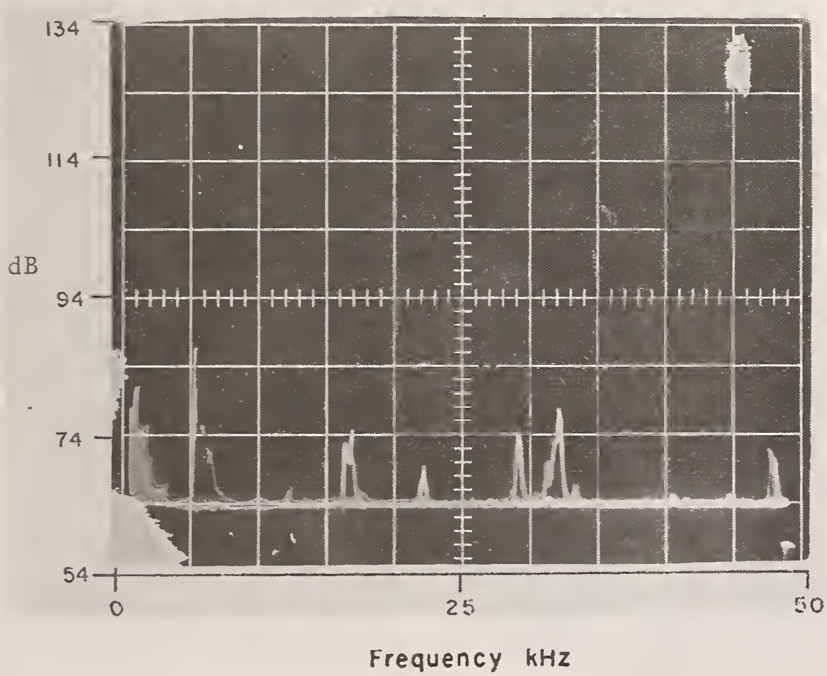


Figure 26. Multiple Sweeps of Acoustical Disturbances from Cutting Maul; Test 3A

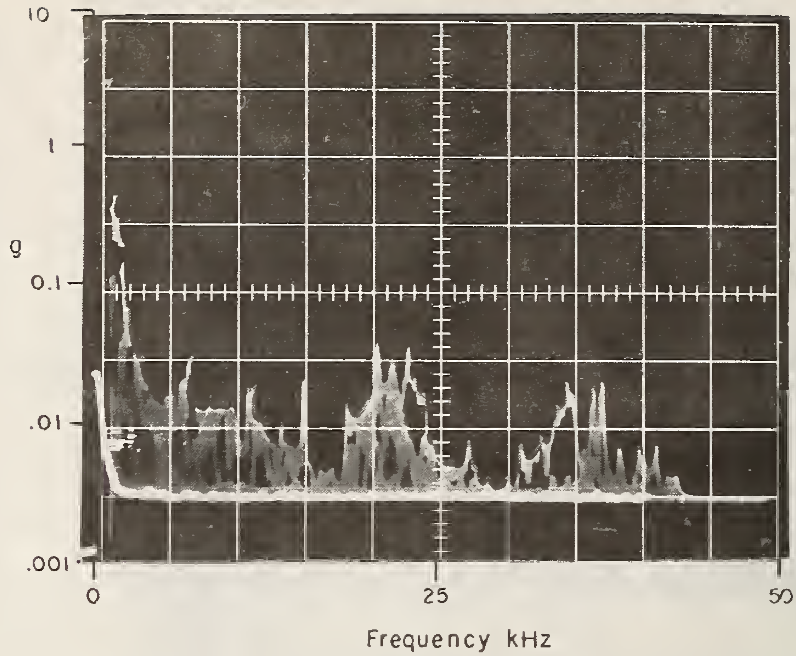


Figure 27. Multiple Sweeps of Vibrational Disturbances from Cutting Maul; Test 3A

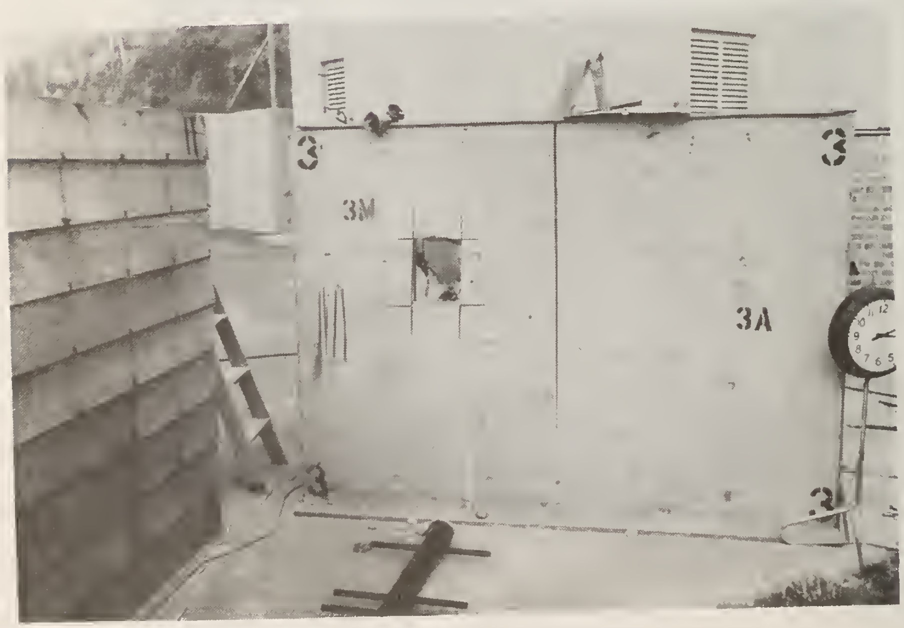


Figure 28. Completed Opening, Test 3MA

5.3 Panel 3

The construction of Panel 3 is shown in figure 24. It represents an experimental concept for reinforcing a hollow concrete block barrier with a variety of different materials which hopefully might have required frequent changes in attack tooling or perhaps even be destructive to tooling. The panel reinforcing proved difficult to fabricate and ranked rather low in cost-effectiveness.

5.3.1 Test 3A

With the 6-pound chopping maul, 80 blows in 2.11 minutes working time produced an opening approximately 6" X 6" in size through the plywood, polyurethane, expanded metal and the outer layer of the concrete block, as shown in figure 25. Multiple sweeps of the acoustical and vibrational disturbances that were produced are shown in figures 26 and 27, respectively. Then, using the forked end of the 50-pound battering ram in a two-man attack for 16 blows, the concrete block was completely broken through and the face of the opening enlarged to 8" X 8". With 27 more blows from the maul and 22 more from the ram, the opening was enlarged to 14" X 7-1/2". Then a few light blows with the 10-pound sledgehammer flattened the broken, expanded metal against the sides of the opening to provide the necessary area (see fig. 28). The total working time was 3.84 minutes and the elapsed time 5.17 minutes.

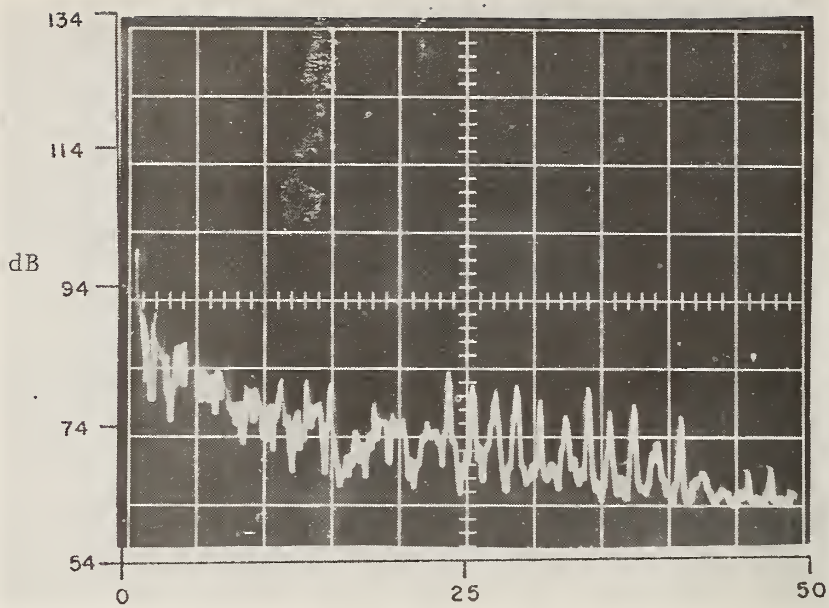
5.3.2 Test 3M

A 14" diameter hubless, gasoline-powered rotary saw with carbide-tipped blade was used to make a test cut. It penetrated the wood, polyurethane and expanded metal readily, but, on encountering the concrete block below this reinforcing, the carbide tips were broken off of all but five of the blade teeth.

5.3.3 Test 3MA

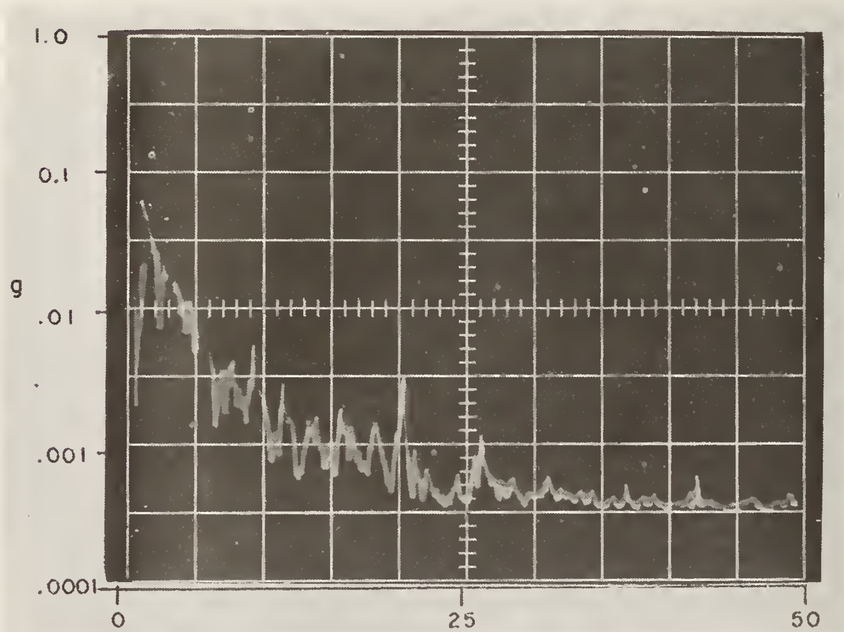
Since test 3M was unsuccessful, a 12" abrasive wheel saw attack was set up as an alternate.

An 8" X 12" rectangular attack area was laid out and the abrasive wheel saw cut through the plywood, expanded metal and polyurethane along this perimeter in 2.51 minutes working time, 4.03 minutes elapsed time. Samples of the acoustic and vibrational disturbances produced are shown



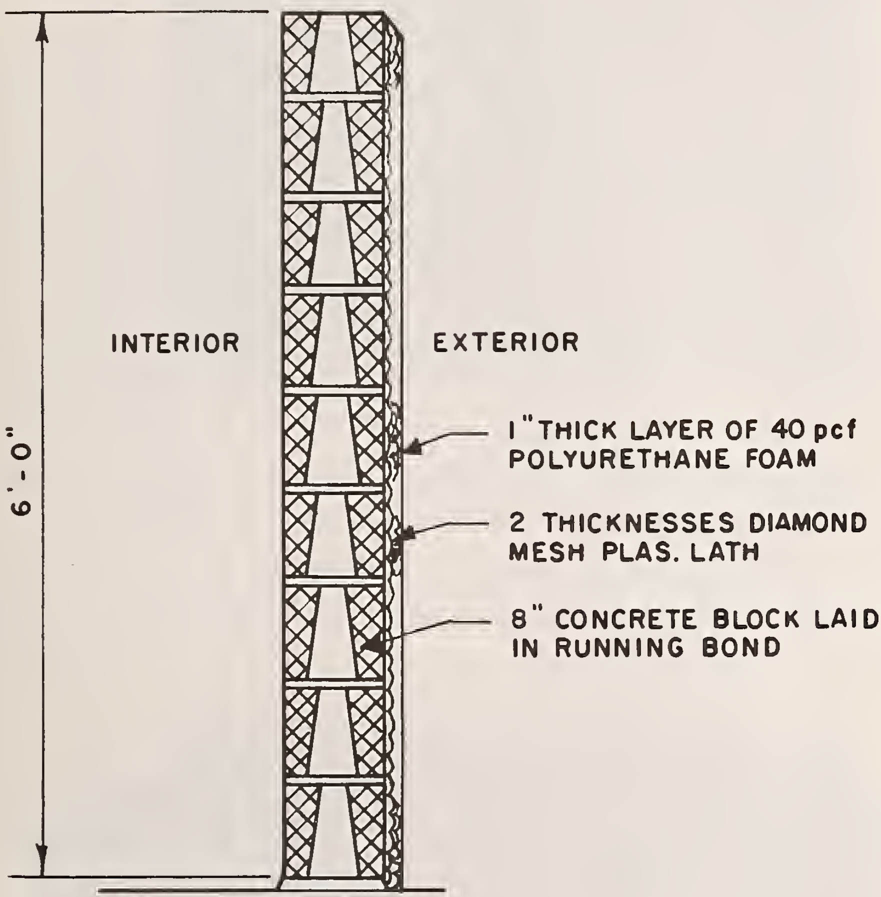
Frequency kHz

Figure 29. Acoustical Disturbances Resulting from Abrasive Wheel Saw; Test 3MA



Frequency kHz

Figure 30. Vibrational Disturbances Resulting from Abrasive Wheel Saw; Test 3MA



PANEL 4

Figure 31. Construction of Panel 4

in figures 29 and 30, respectively. Sawing was then continued into the concrete block to the maximum depth permitted by the abrasive wheel which was about 3". This extended the working time to a total of 8.31 minutes. Then, using a crowbar for 0.4 minute, the plywood, polyurethane and expanded metal plug was pried off of the wall. There was rather poor adhesion between the polyurethane and the concrete block.

Nineteen blows with the 50-pound battering ram cleared the concrete block from the opening. The total working time was 9.17 minutes and the elapsed time was 11.17 minutes. The attack could probably have proceeded much more rapidly if the 5.80 minutes spent cutting the concrete block with the abrasive wheel saw had been omitted.

5.4 Panel 4

The construction of Panel 4 is shown in figure 31. It was similar to Panel 3 but did not employ the outer layer of plywood and had two layers of metal plaster lath in place of the 3/4" No. 9 expanded metal. The difficulty of fabrication is evidenced by the condition of the reinforcing materials prior to the attacks as shown in figure 32. The attacks scheduled for locations 4A and 4B were exchanged as a convenience to the operators to provide more clearance for attack tooling.

Figure 32. Panel 4 Prior to Tests

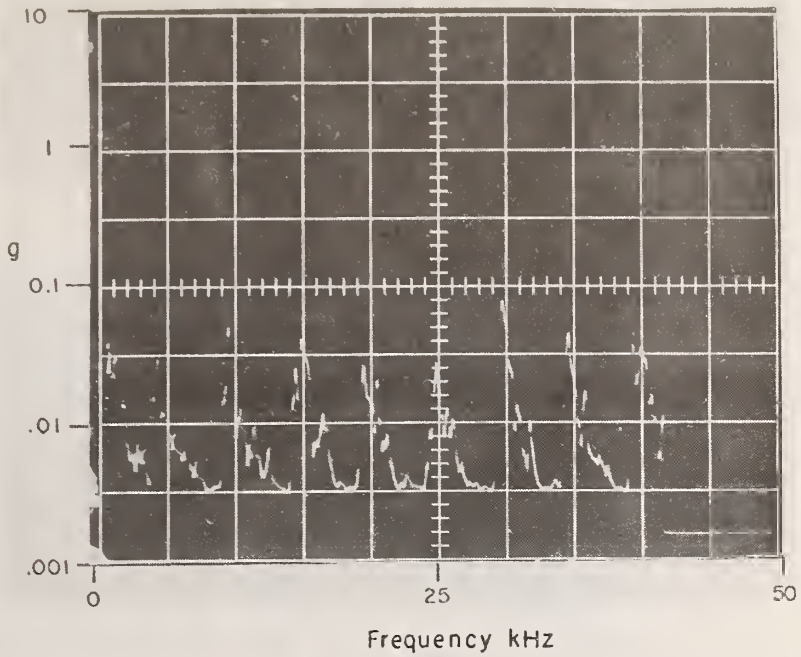


Figure 33. Vibrational Disturbances Produced by Rotohammer's 1-1/2" Toothed Chisel; Test 4A

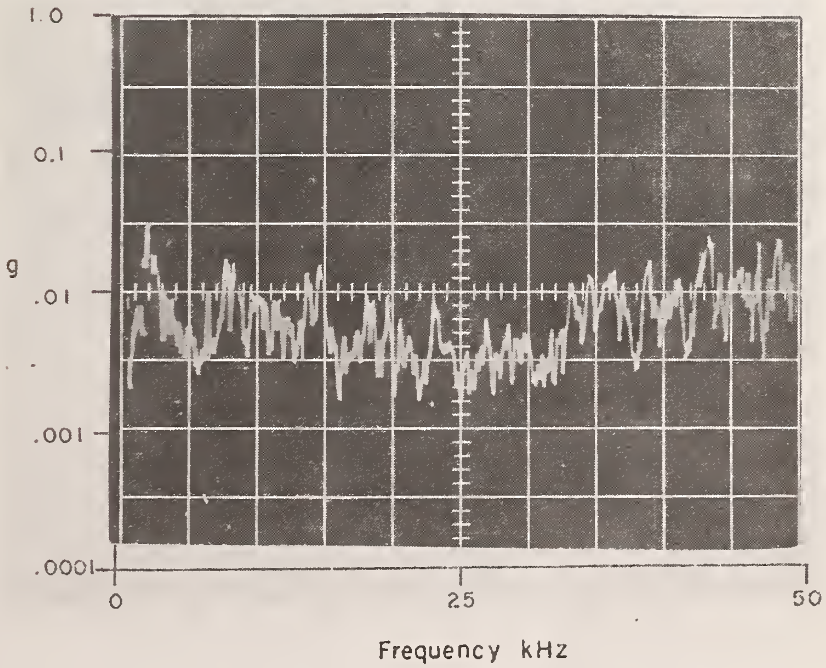


Figure 34. Vibrational Disturbances Produced by 14" Gasoline-Powered Wheel Saw; Test 4A

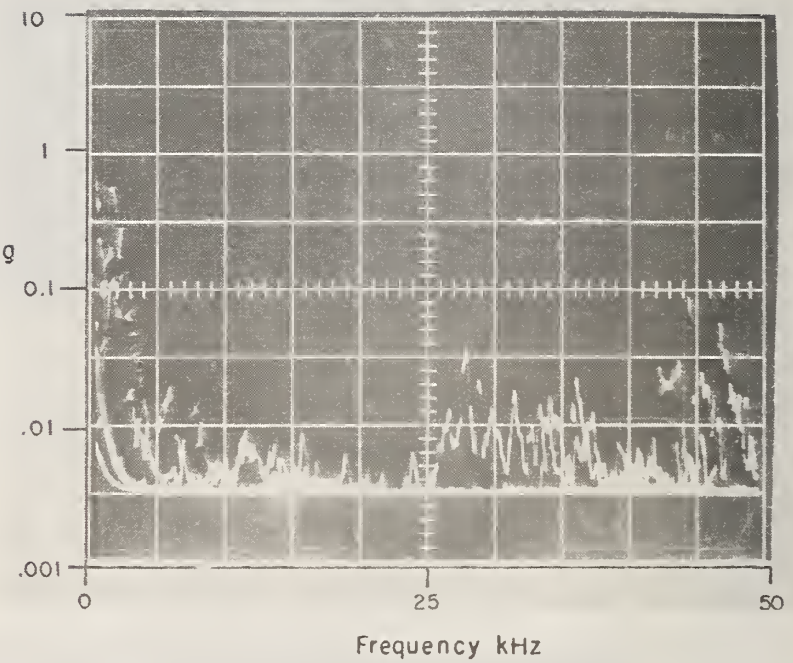


Figure 35. Multiple Sweeps of Vibrational Disturbances Resulting from Use of 6-lb. Chopping Maul; Test 4B

5.4.1 Test 4A

The rotohammer, equipped with a 1-1/2" toothed chisel, was used in an attempt to cut through the polyurethane and metal lath around the perimeter of the target area. After 30 seconds the chisel broke. Just prior to the break, the vibrational disturbances shown in figure 33 were observed.

A new test was then started at this location using the 14" gasoline-powered abrasive wheel saw. In 6.77 minutes working time the target area perimeter had been cut to a depth ranging from 4-1/4" to 5" through the polyurethane, metal lath and concrete block. Samples of the vibrational disturbances are shown in figure 34. SPL readings of 102 to 106 dB were observed at a distance of 12'.

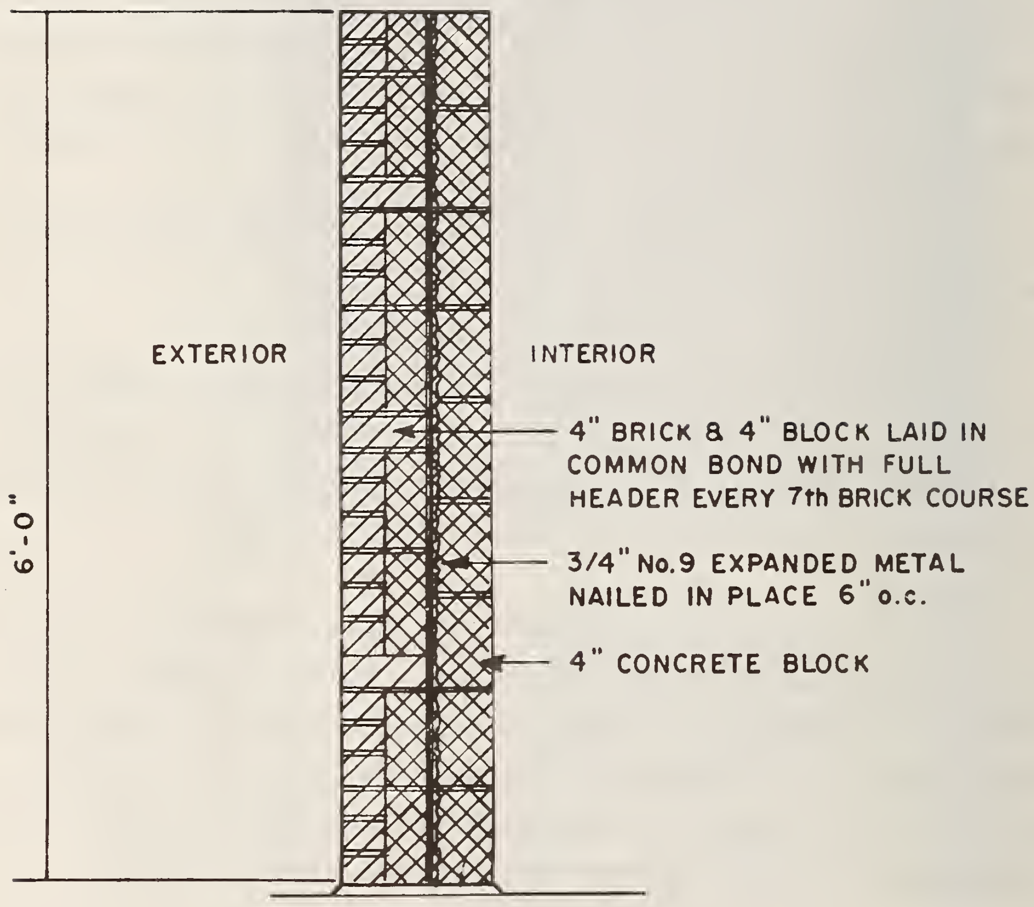
Then 14 blows with the 26-pound bar cleared the opening with a total working time of 7.87 minutes.

5.4.2 Test 4AM

The test was then repeated except that the abrasive wheel saw was used to cut only through the polyurethane and metal lath. Thirty-five blows from the 26-pound bar completed the opening in a total working time of 2.64 minutes and elapsed time of 2.66 minutes.

5.4.3 Test 4B

Using the 6-pound chopping maul, 40 blows effectively cleared the reinforcing materials from the target area. Multiple sweeps of the vibrational disturbances are shown in figure 35. Then 33 blows with the 10-pound sledgehammer cleared the concrete away making the complete penetration in 1.9 minutes working time and 2.83 minutes elapsed time. SPL readings of 84 to 89 dB were observed at a distance of 12'.



PANEL 5

Figure 36. Construction of Panel 5

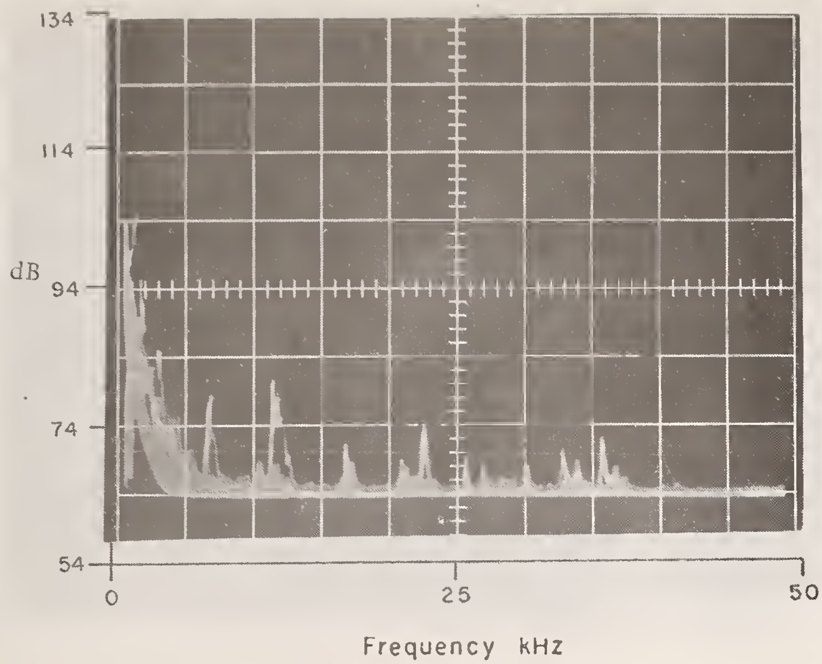


Figure 37. Multiple Sweeps of Acoustical Disturbances Produced by 10 lb. Sledgehammer; Test 5A

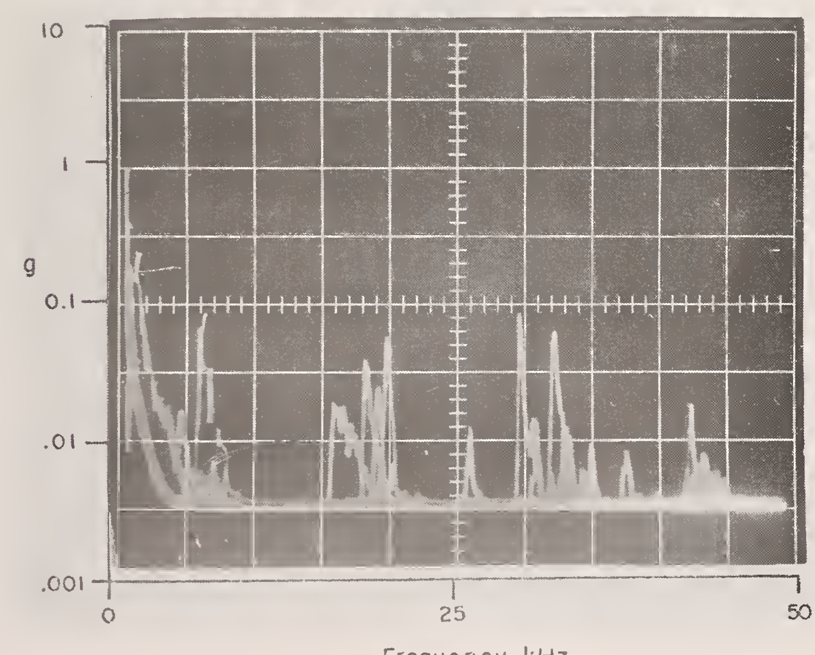


Figure 38. Multiple Sweeps of Vibrational Disturbances Produced by 10 lb. Sledgehammer; Test 5A

5.5 Panel 5

The construction of Panel 5 is shown in figure 36. Reinforcing has been applied to the interior of the wall in the form of a layer of expanded metal and 4" thick concrete block.

5.5.1 Test 5A

The 10-pound sledgehammer was used to attack the target area. Multiple sweeps of the acoustical disturbances are shown in figure 37 and the vibrational disturbances in figure 38. SPL readings of 84 to 95 dBC were observed at 12'. Initial breakthrough occurred after 2.66 minutes working time and 106 blows. Forty-six more blows enlarged the opening to an oval shape approximately 14" X 9" and flattened the expanded metal against the sides of the hole. The final opening is shown in figure 39.

Figure 39. Opening Produced by Test 5A

Figure 40. Test 5K. Battering Ram
Suspended from A-Frame

Figure 41. Test 5K. Single Man Using Suspended
Battering Ram, Raising Center of
Gravity 24"

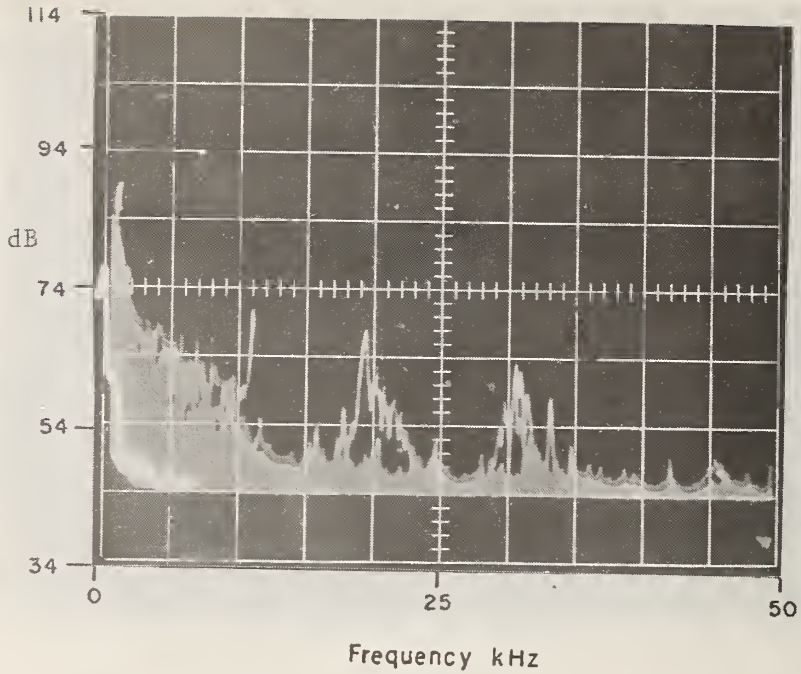


Figure 42. Multiple Sweeps of Acoustical Disturbances Produced by Ram ; Test 5K

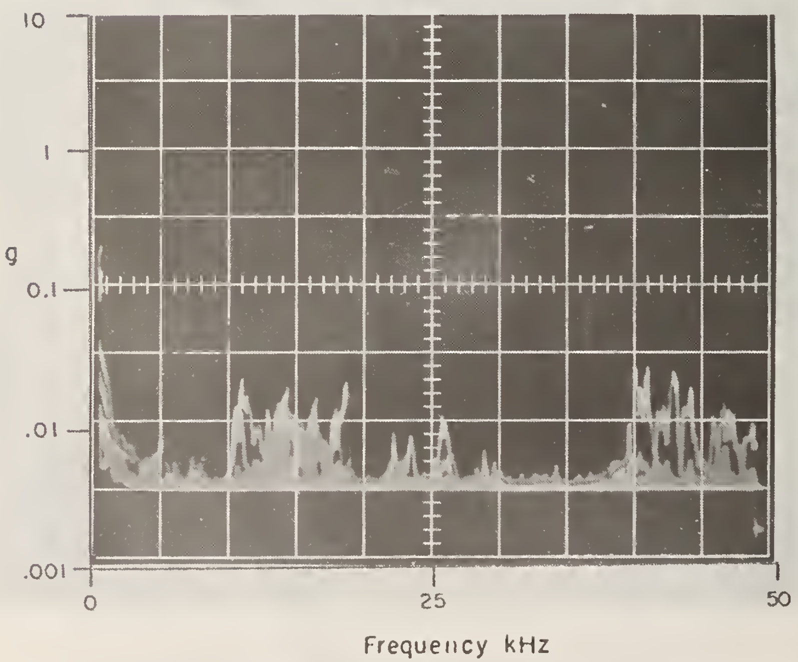


Figure 43. Multiple Sweeps of Vibrational Disturbances Produced by Ram; Test 5K

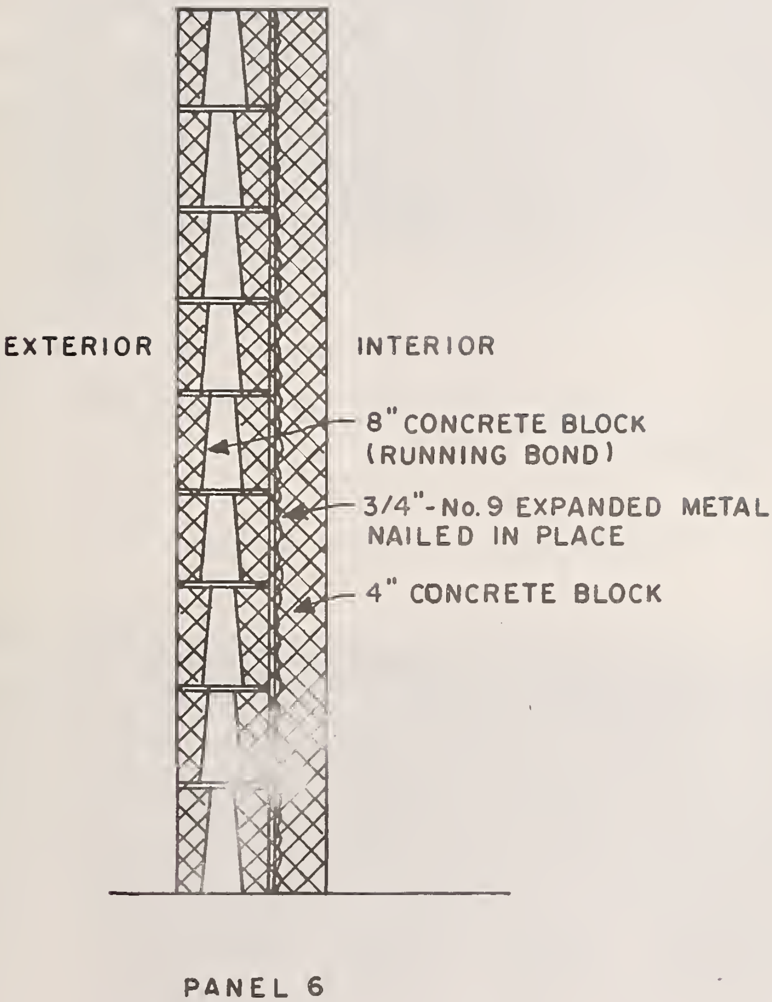


Figure 44. Construction of Panel 6

5.5.2 Test 5K

An A-frame was assembled from a pair of 2" X 4" X 10' planks and clamped to the panel. The 50-pound battering ram was suspended from the apex of this structure as shown in figure 40. Using this arrangement, a single man could raise the center of gravity of the ram approximately 24" as shown in figure 41 and deliver a series of fairly reproducible blows. An opening of about 15" X 5" was broken through after 66 such blows delivered in 5.10 minutes working time. Then the ram suspension ropes were shortened slightly and another 19 blows were delivered to enlarge the vertical dimensions of the opening. Multiple sweeps of the acoustical disturbances produced by the ram are shown in figure 42 and the vibrational disturbances in figure 43. SPL values of 94 to 95 dBC were observed at a distance of 10'.

Finally, the 10-pound sledge was used for 25 blows to complete the development of a 12" X 9" clear opening through the flattened, expanded metal. The total working time was 7.53 minutes. The elapsed time was not recorded.

5.6 Panel 6

The construction of Panel 6 is shown in figure 44.

5.6.1 Test 6B

Using the rotohammer and 3/4" drill, eight equally spaced holes were made around the perimeter of the target circle to a depth of 8". A similar ninth hole was made in the center of the circle. This 72" of drilling was accomplished in 2.06 minutes working time at an average rate of 1.7 seconds per inch. Samples of the acoustical and vibrational disturbances which were produced are shown in figures 45 and 46, respectively. SPL readings of 92 to 95 dB were observed at a distance of 12'.

Then the inner reinforcing layer of 4" concrete block was spalled out using a punch driven by the 10-pound sledgehammer into the bottom of each of the drilled holes. This required a total of 112 blows delivered in an additional 2.25 minutes of working time. It produced SPL readings of 73 to 76 dB and acoustical and vibrational disturbances as shown in the multiple sweep traces of figures 47 and 48, respectively.

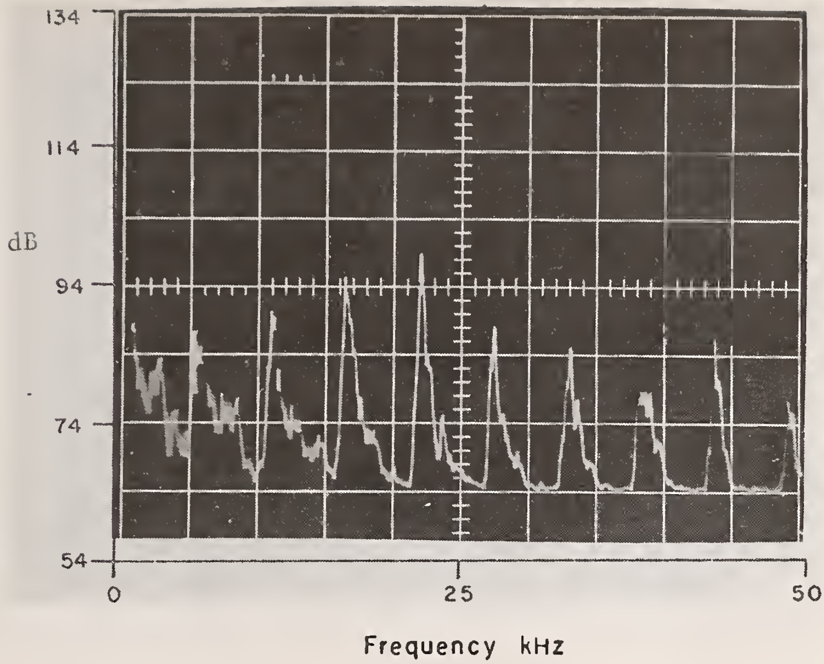


Figure 45. Acoustical Disturbances Produced by Rotohammer and 3/4" Drill; Test 6B

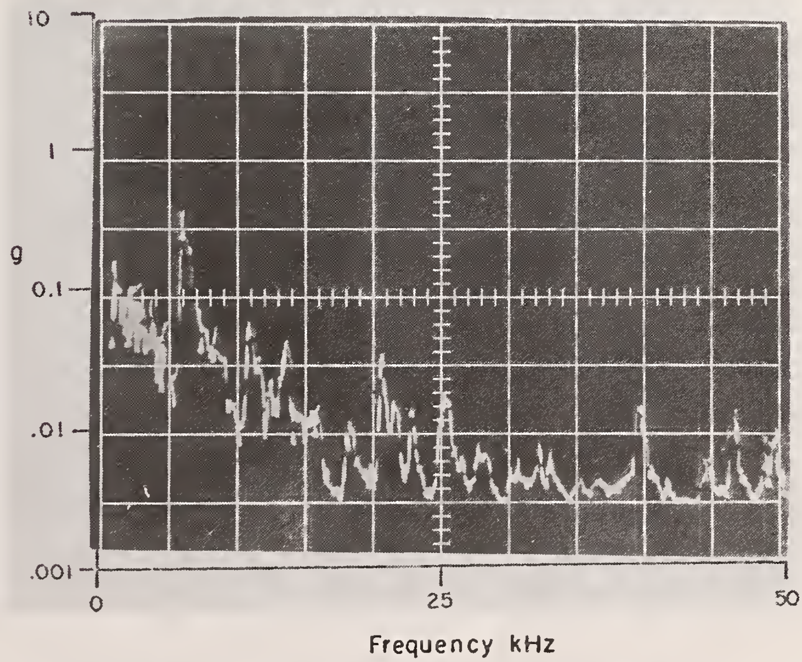


Figure 46. Vibrational Disturbances Produced by Rotohammer and 3/4" Drill; Test 6B

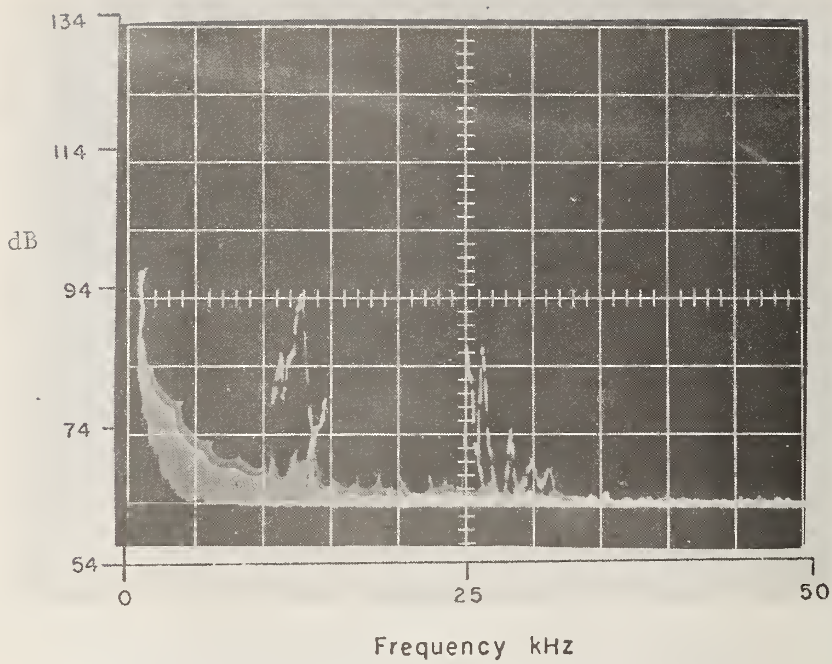


Figure 47. Multiple Sweeps of Acoustical Disturbances Produced by Punch and 10 lb. Sledgehammer; Test 6B

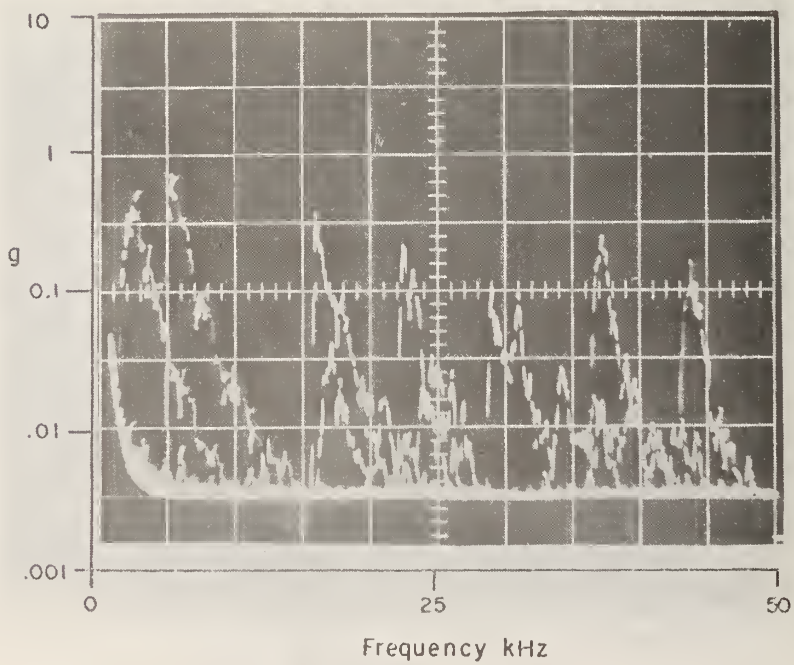


Figure 48. Multiple Sweeps of Vibrational Disturbances Produced by Punch and 10 lb. Sledgehammer; Test 6B

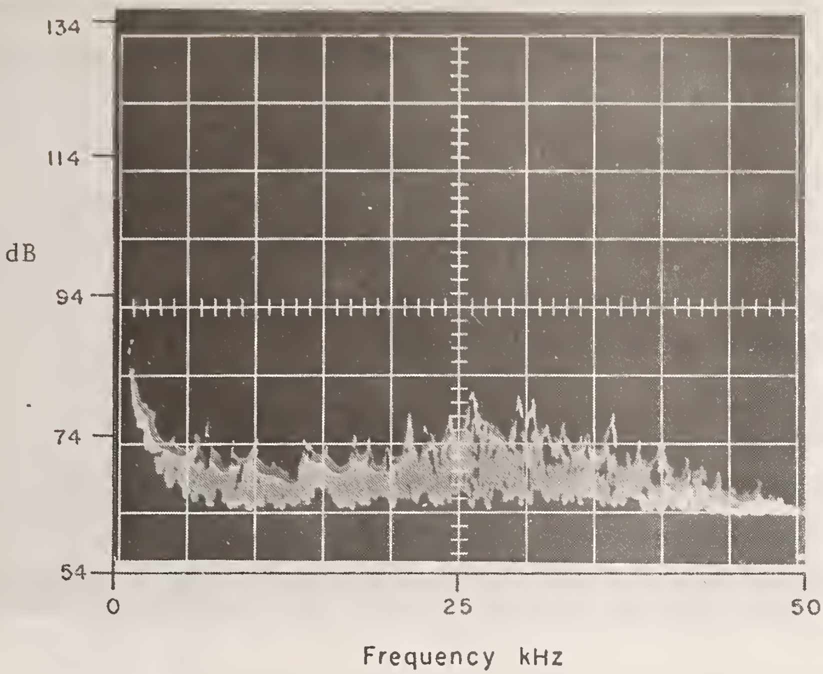


Figure 49. Acoustical Disturbances Resulting from Oxyacetylene Cutting Torch; Test 6B

Figure 50. Opening Produced by Test 6B

Next, the 10-pound sledge was used to break out the exterior concrete block to expose the expanded metal. This required 80 blows and 2.62 minutes of working time. Then the oxyacetylene cutting torch was used for 3.74 minutes to cut the expanded metal around the periphery of the opening. It produced acoustical disturbances as shown in figure 49.

A final 0.20 minute with the 26-pound bar produced the completed opening shown in figure 50 with a total working time of 10.87 minutes and elapsed time of 14.45 minutes.

5.6.2 Test 6K

The 50-pound battering ram was supported by its handles by two men and was swung for 155 blows in 3.17 minutes working time to produce an opening with external dimensions of approximately 16" X 24". Then, No. 14 bolt cutters were used to cut the expanded metal. This required 1.74 minutes for a total working time of 4.91 minutes and 6.40 minutes of elapsed time and produced a clear opening of 10" X 12" as shown in figure 51.

Figure 51. Opening Produced by 50-lb. Battering Ram and No. 14 Bolt Cutters; Test 6K

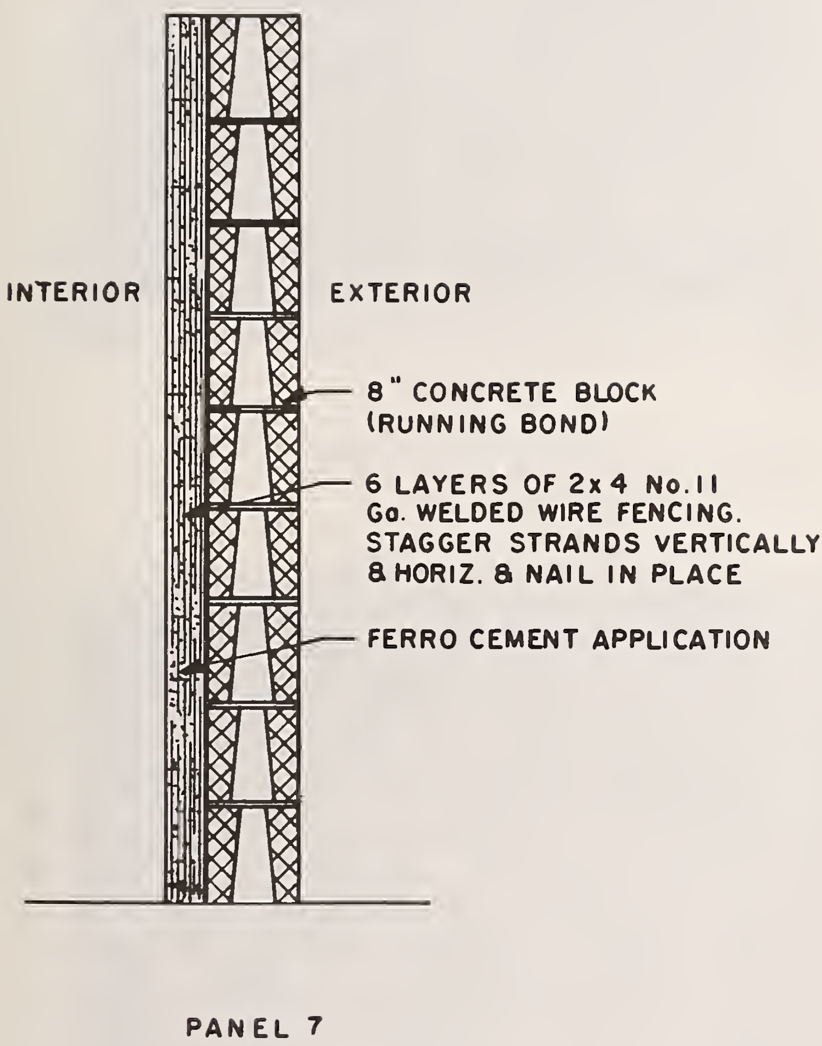


Figure 52. Construction of Panel 7

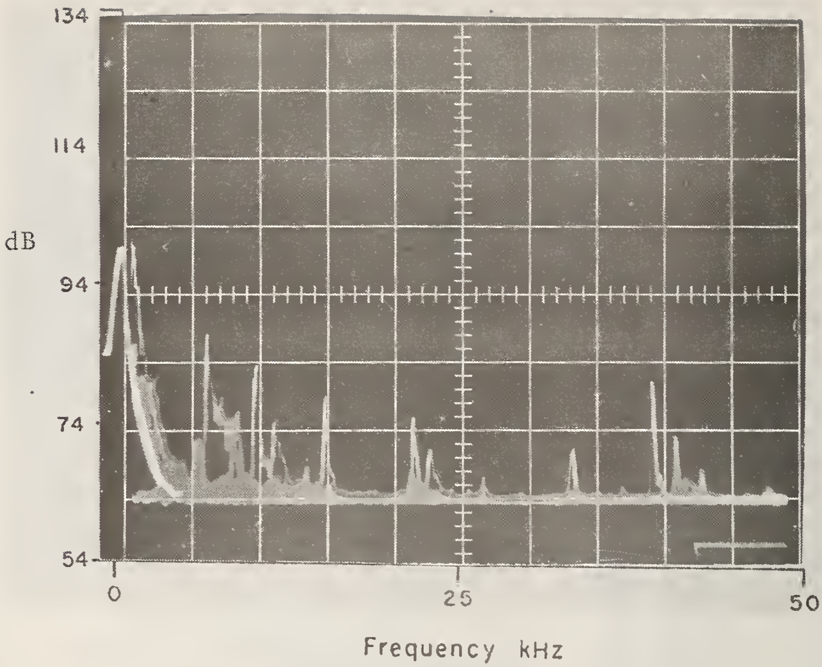


Figure 53. Multiple Sweeps of Acoustical Disturbances Produced by 10 lb. Sledgehammer; Test 7A

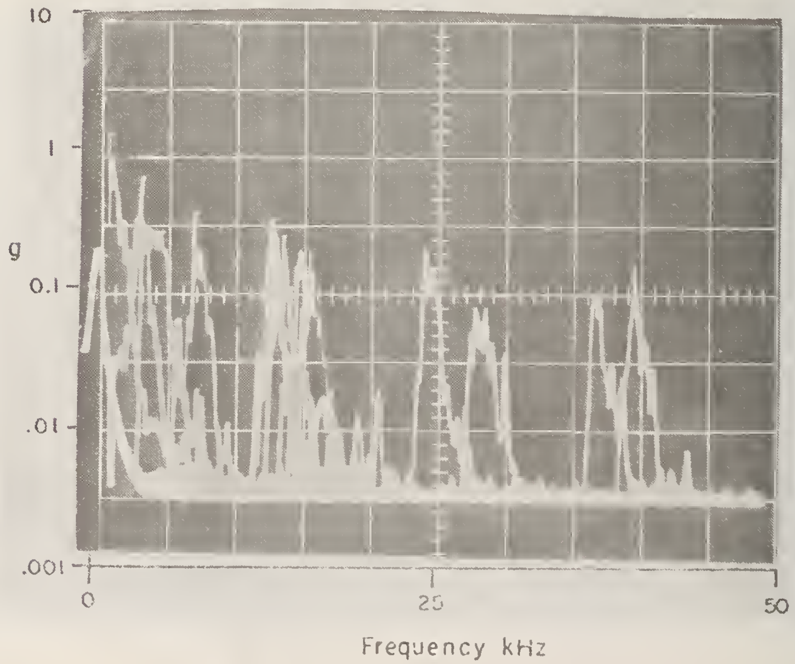


Figure 54. Multiple Sweeps of Vibrational Disturbances Produced by 10 lb. Sledgehammer; Test 7A

Figure 55. Test 7A with Ferro-cement Reinforcing Wires Exposed

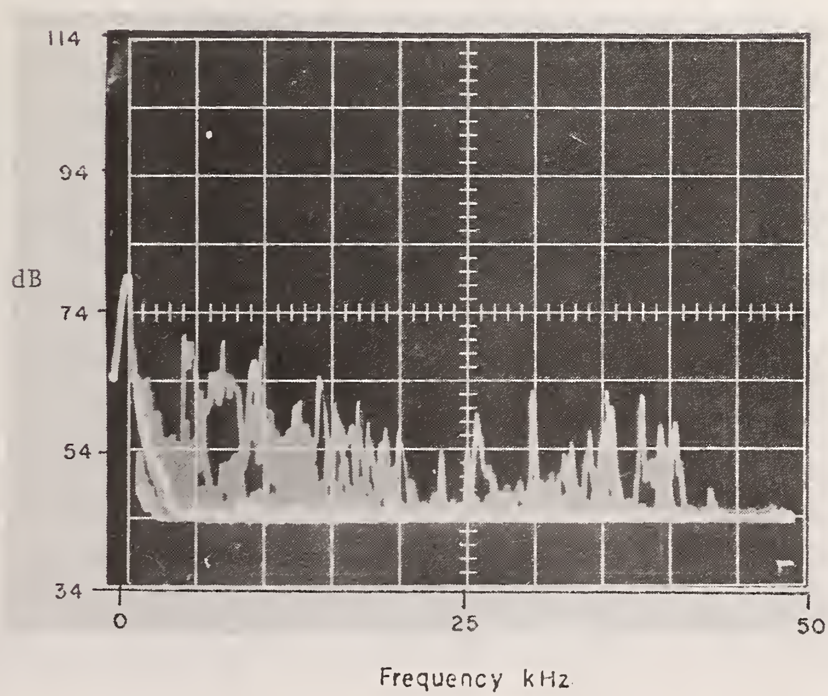


Figure 56. Acoustical Disturbances Produced by No. 14 Bolt Cutters; Test 7A

5.7 Panel 7

The construction of Panel 7 is shown in figure 52. The mix formulation used in this and the other panels which were reinforced with ferro-cement was obtained from a manufacturer of ferro-cement boat hulls. It is shown in table 1.

At the time that the reinforcing was applied to Panel 7, three samples of the material were cast. These were tested on the same day that Panel 7 was tested and developed an average compression strength of 7780 p.s.i.

Table 1. Ferro-cement Mix

Water	40 lb.
Portland Cement	94 lb.
Sand	150 lb.
Pozzolan Densifier	15 lb.

5.7.1 Test 7A

The initial attack was with the 10-pound sledgehammer. Multiple sweep examples of the acoustical and vibrational disturbances are shown in figures 53 and 54, respectively. After 130 blows delivered in 3.0 minutes working time, the front face of the concrete block had been broken out in an area approximately 18" X 24" in size to a depth of about 6-1/2". During this portion of the attack, SPL readings of 82 to 94 dBC were observed at a distance of 12'. Then, 40 blows with the 6-pound cutting maul and 80 blows with the 26-pound bar produced the opening shown in figure 55. At this point the total working time was 5.40 minutes and the elapsed time was 7.15 minutes.

The six layers of 2" X 4", No. 11 wire fencing were then cut with No. 14 bolt cutters to make a clear 15" X 10" aperture. This required 105 cuts which took 5.30 minutes to make for an average of 3 seconds per cut. Samples of the acoustical and vibrational disturbances produced by the bolt cutters are shown in figures 56 and 57, respectively. The total working time required for this penetration was 10.70 minutes and the elapsed time was 14.50 minutes.

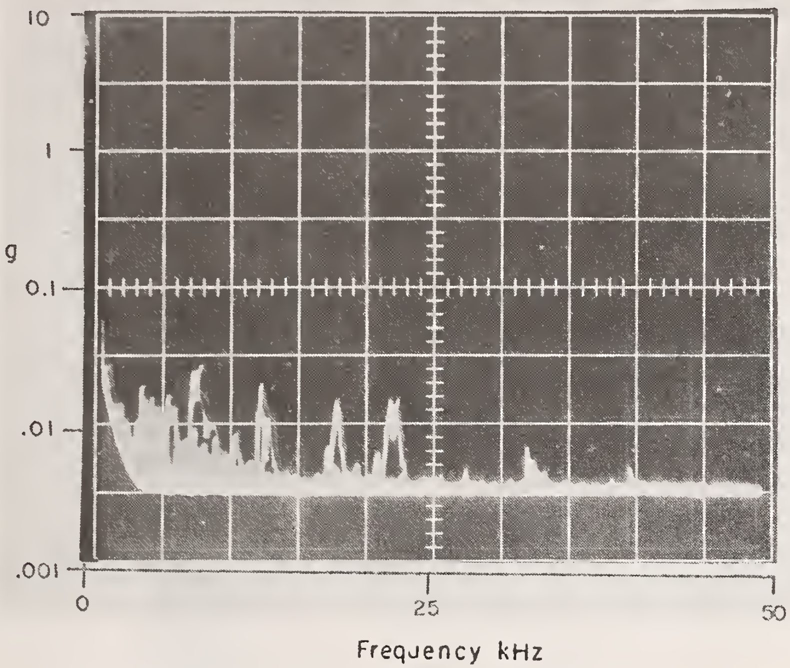


Figure 57. Vibrational Disturbances Produced by No. 14 Bolt Cutters; Test 7A

Figure 58. Test 7A. Cutting Wires with Torch for Time Comparison

Because of the relatively large amount of time used with the bolt cutters, it was decided to check alternative techniques which might have been used to cut the reinforcing wires. The opening in the concrete block was enlarged a bit and 20 linear inches of reinforcing wire was cut using the abrasive wheel cutoff saw. The rate was 2.35 seconds per inch, thus the 40-inch perimeter of an 8" X 12" opening could have been cut in 0.9 minute and Test 7A could have been completed in 6.30 minutes working time using this technique.

Finally, the oxyacetylene cutting torch was used in a similar test as shown in figure 58. The measured cutting rate was 13.26 seconds per linear inch and test 7A could have been completed in 9.82 minutes using this approach.

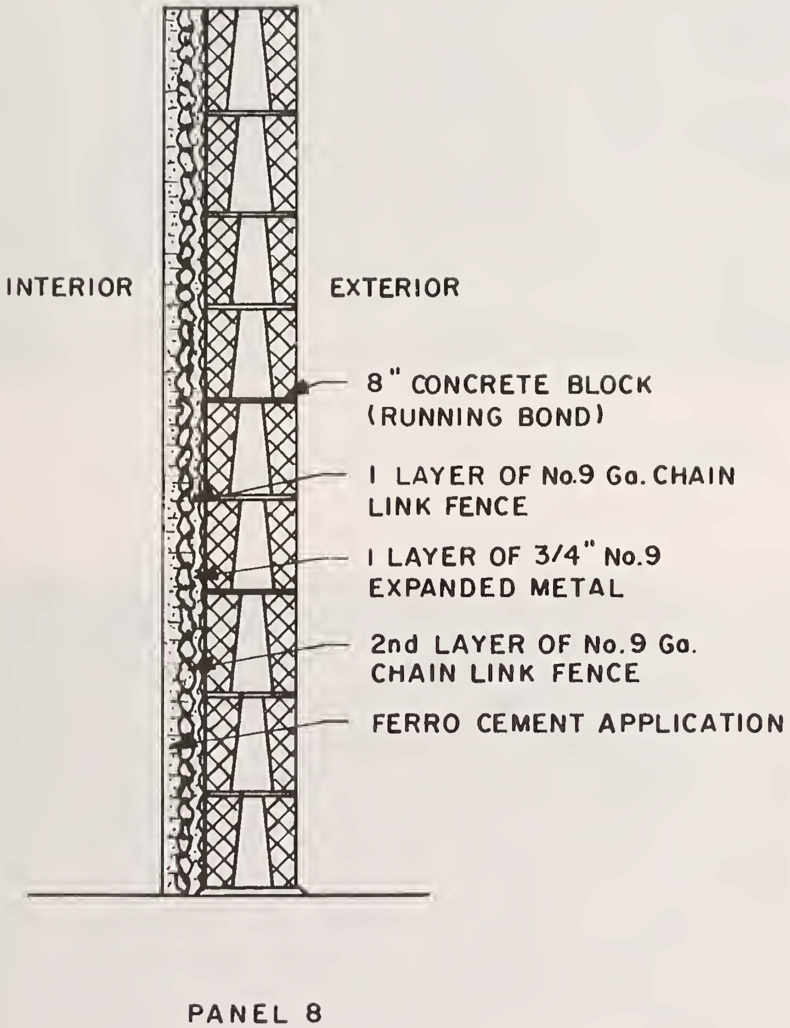


Figure 59. Construction of Panel 8

Figure 60. Test 8A, Beginning of Attack

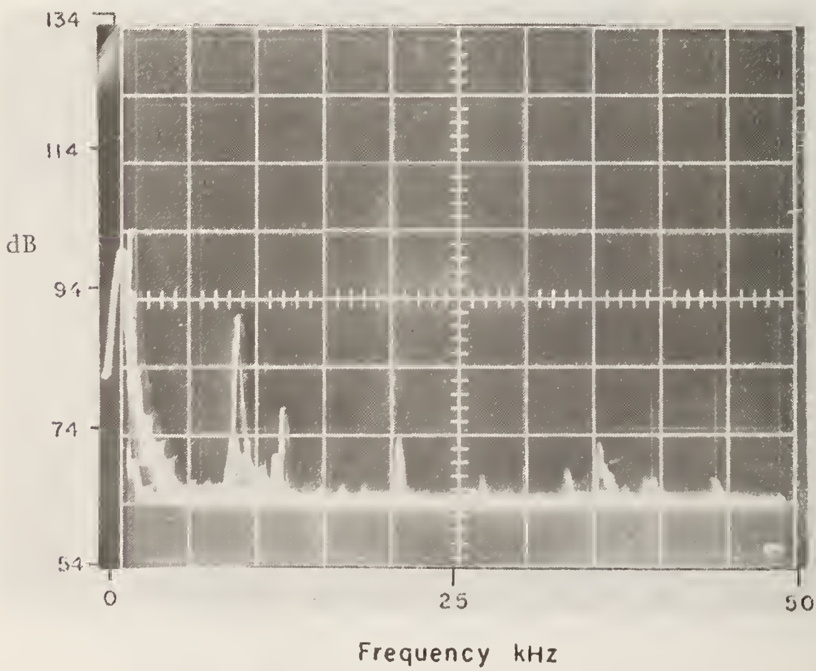


Figure 61. Acoustical Disturbances Resulting from 10-lb. Sledgehammer Attacks; Test 8A

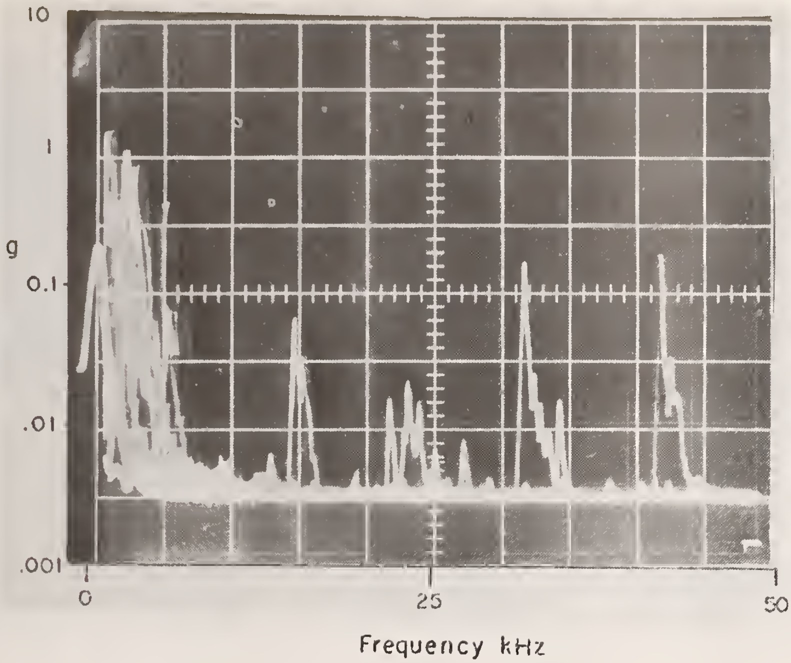


Figure 62. Vibrational Disturbances Resulting from 10-lb. Sledgehammer Attacks; Test 8A

Figure 63. Opening Produced in Test 8A

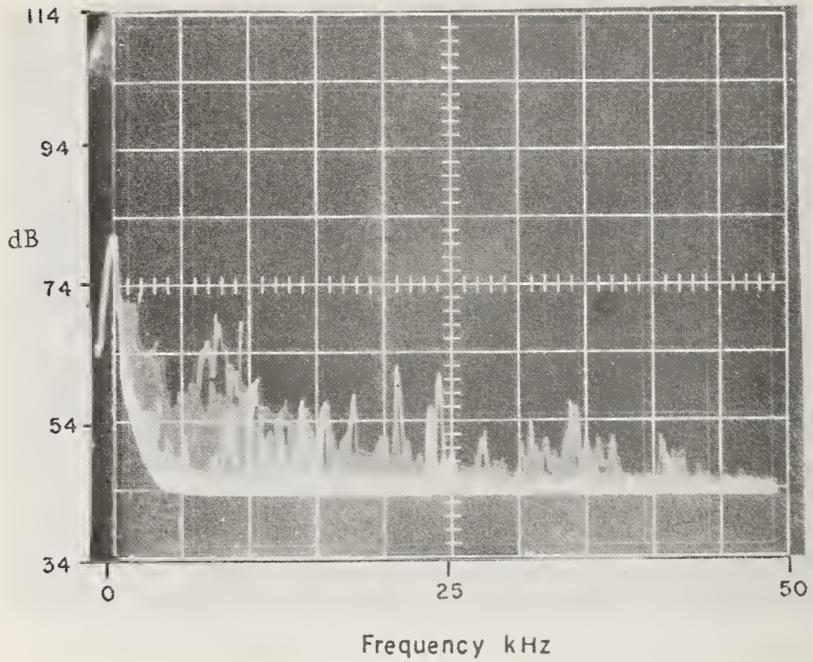


Figure 64. Acoustical Disturbances from Bolt Cutters; Test 8A

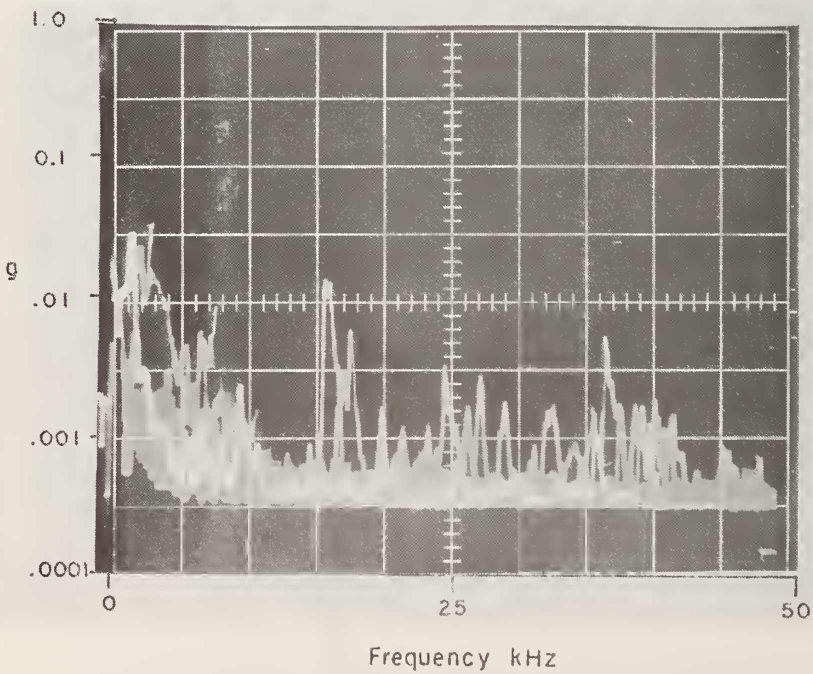


Figure 65. Vibrational Disturbances from Bolt Cutters; Test 8A

Figure 66. Test 8A3, Abrasive Wheel Saw

Figure 67. Opening Produced by 14"
Abrasive Wheel Saw; Test 8A3

5.8 Panel 8

As shown in figure 59, Panel 8 is similar to Panel 7 except for reinforcing configuration in the ferro-cement liner.

5.8.1 Test 8A

In a manner similar to that employed in Test 7A, the 10-pound sledgehammer was used to break out the concrete block (see fig. 60). Acoustical and vibrational disturbances are shown in figures 61 and 62, respectively.

After 120 blows with the sledgehammer, the 26-pound bar was used for 80 blows to develop an opening of approximately 20" X 10" in which the cement had all been spalled clear of the reinforcing materials. This required 4.52 minutes of working time. Then the No. 14 bolt cutters were used to cut the chain-link fencing and the expanded metal reinforcing. The outer layer of chain-link fabric required 31 cuts which were made in 1.25 minutes. The expanded metal took 59 cuts made in 3.33 minutes and the inner layer of chain-link fabric took only 16 cuts made in 1.23 minutes as this layer could then be folded back leaving a clear opening of 8" X 15" as shown in figure 63. Samples of the acoustical and vibrational disturbances are shown in figures 64 and 65, respectively. The total working time for this test was 10.33 minutes and the elapsed time was 12.66 minutes.

5.8. 2 Test 8A3

Because the abrasive wheel saw had shown good performance in cutting the ferro-cement reinforcing in Test 7A, it was decided to make a second test on Panel 8 and use it here. A 24" X 32" target was laid out and the front face and webs of the concrete block were broken out with the 10-pound sledgehammer in 119 blows and 2.63 minutes working time. SPL readings of 84 to 88 dBC were observed at a distance of 12' during this activity. This oversize opening, as shown in figure 66, was necessary to provide room for the hub of the abrasive wheel saw. The 14" abrasive wheel was used to cut the interior face of the concrete block and the ferro-cement liner. At the end of 9.83 minutes working time and 12.70 minutes elapsed time, an opening 14" X 16" had been produced as shown in figure 67. Samples of the acoustical and

vibrational disturbances produced by the abrasive wheel saw are shown in figures 68 and 69, respectively. SPL readings of 99 dBC were observed at a distance of 12'.

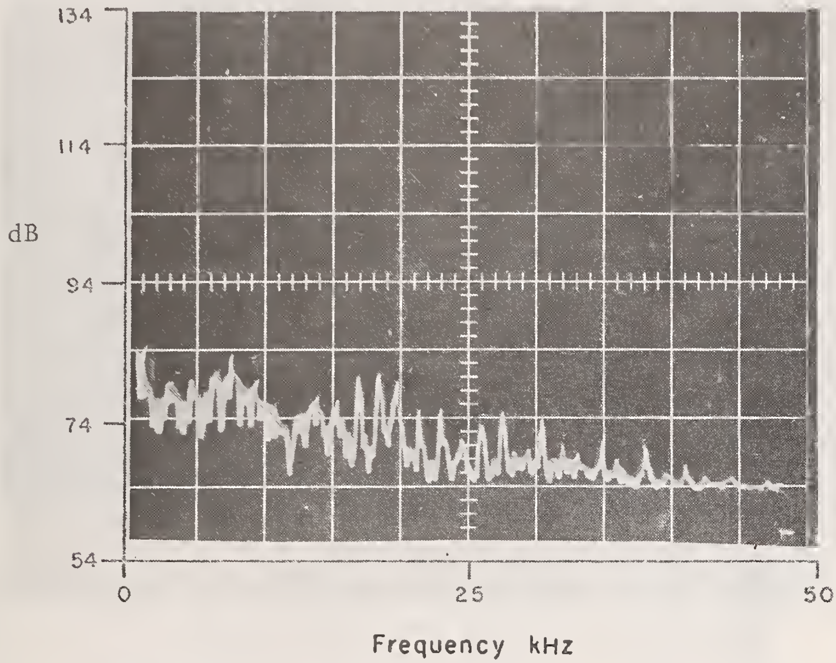


Figure 68. Acoustical Disturbances Produced by Abrasive Wheel Saw; Test 8A3

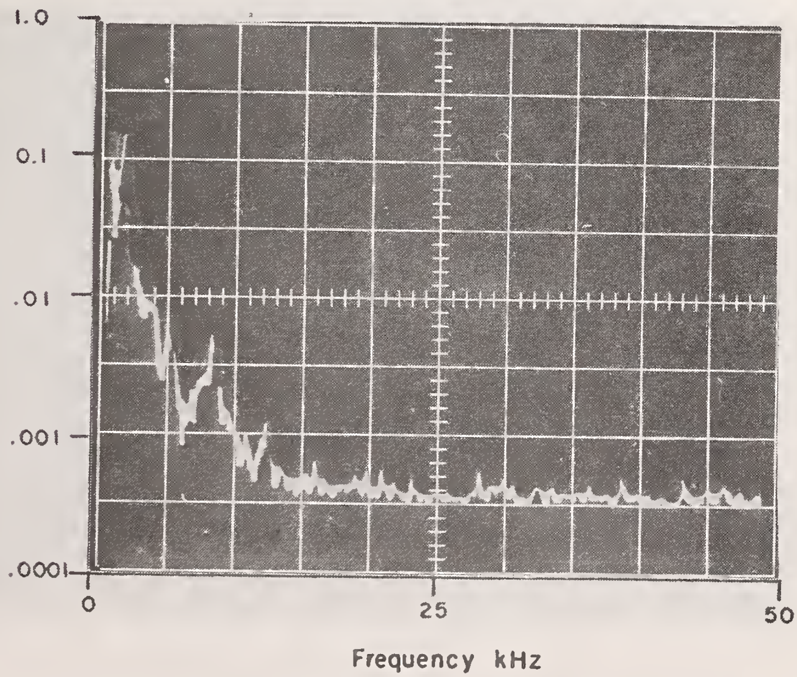


Figure 69. Vibrational Disturbances Produced by Abrasive Wheel Saw; Test 8A3

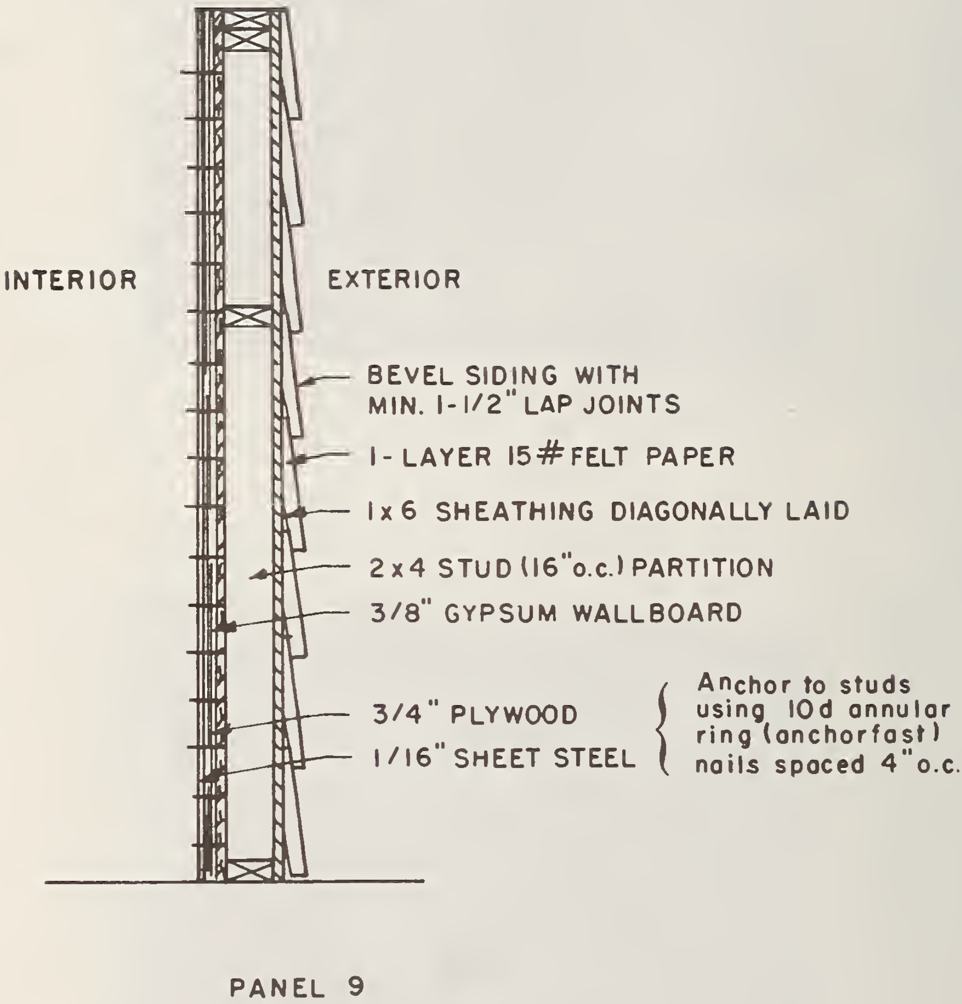


Figure 70. Construction of Panel 9

Figure 71. Panel 9. Hubless Saw Attack;
Test 9M

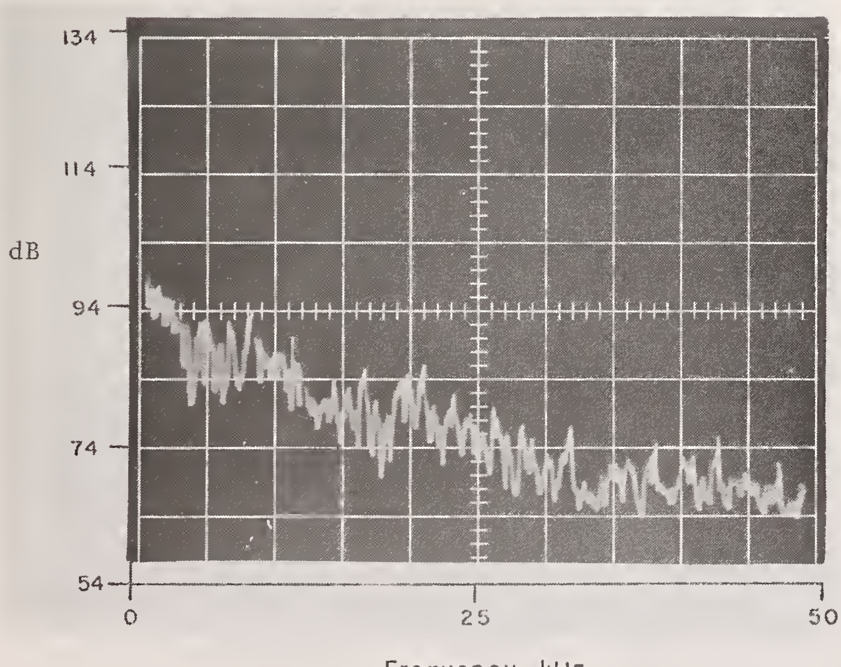


Figure 72. Acoustical Disturbances
Produced by Saw; Test 9M

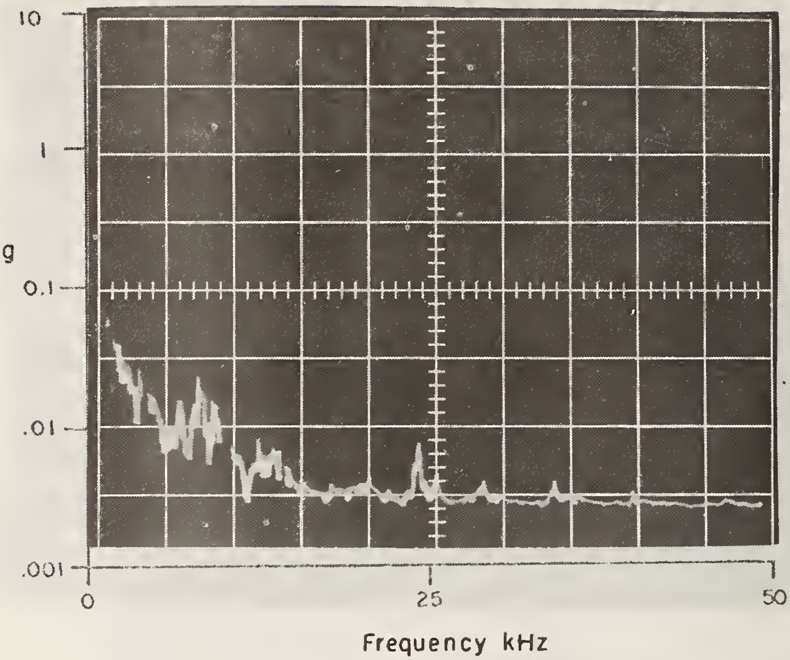


Figure 73. Vibrational Disturbances Produced by Saw; Test 9M

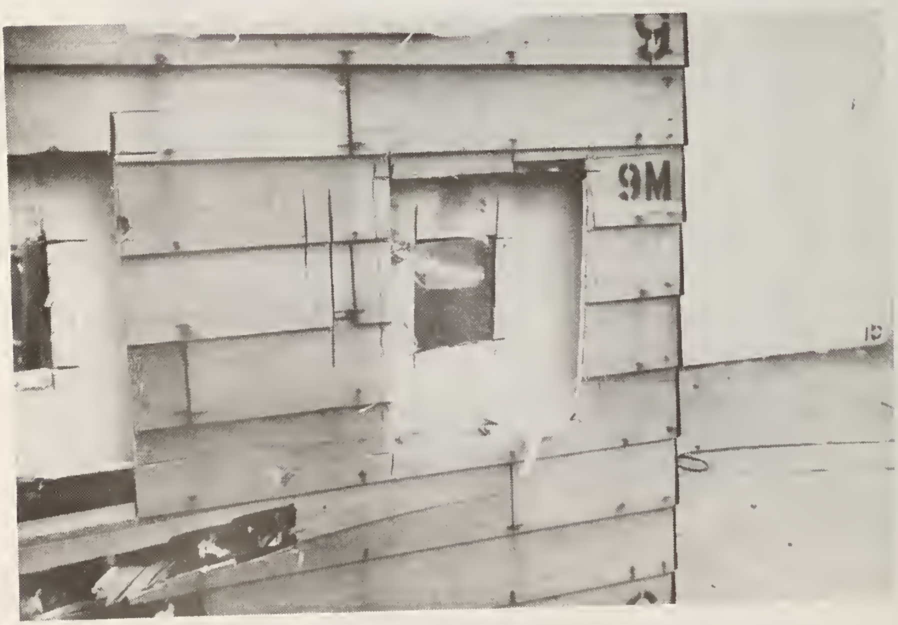


Figure 74. Test 9M. Completed Opening

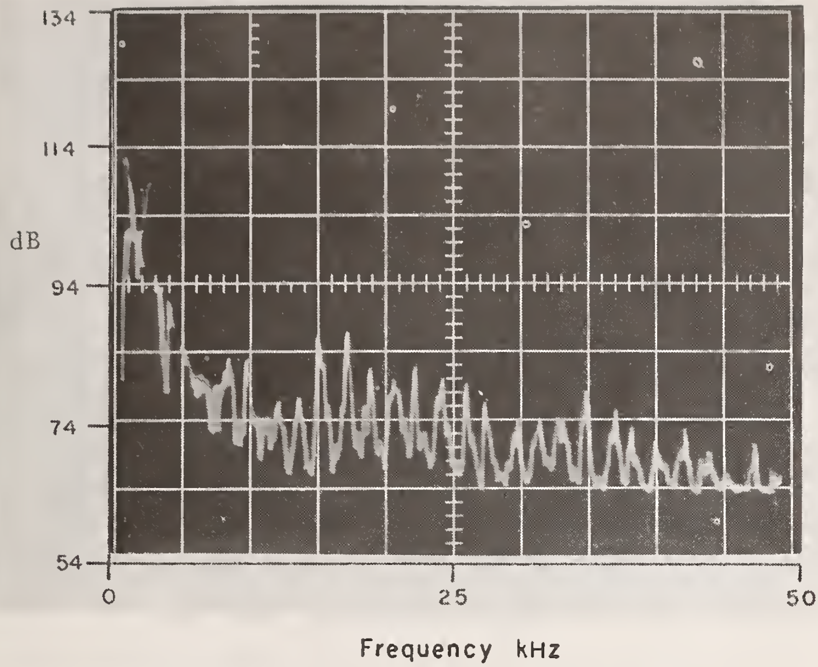


Figure 75. Acoustical Disturbances Produced by Abrasive Wheel Saw; Test 9M

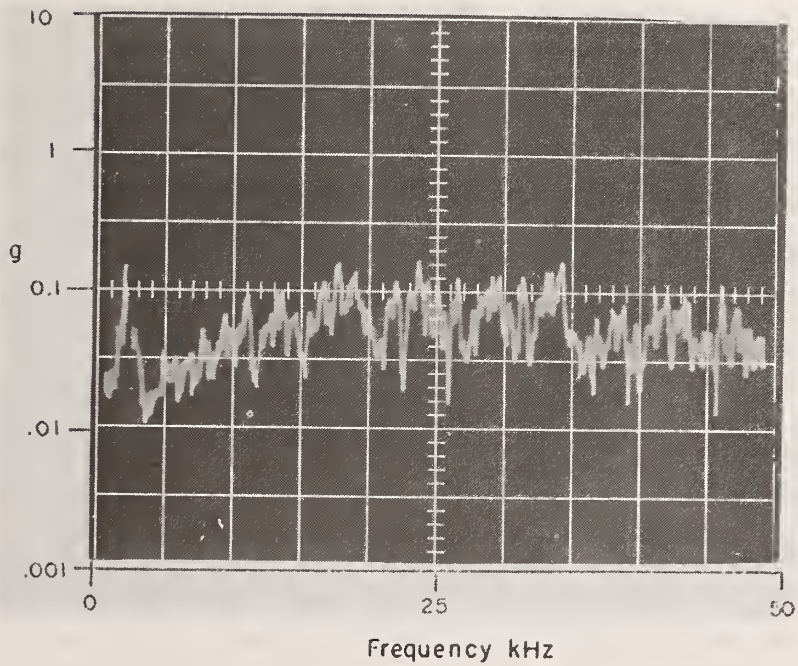


Figure 76. Vibrational Disturbances Produced by Abrasive Wheel Saw; Test 9M

5.9 Panel 9

Figure 70 shows the construction of Panel 9. It represents one of the four alternate methods which were used to increase the penetration resistance of a typical wooden wall.

5.9.1 Test 9M

Despite the fact that the gasoline-powered hubless saw blade had been damaged in an earlier test when many of the carbide tooth points had been knocked off, it was used on this test to make an oversized cut through the bevel siding and planking on the outside of the panel.

Figure 71 shows the operator preparing to begin the attack. Acoustical and vibrational disturbances produced by the saw are shown in figures 72 and 73, respectively. SPL readings were 102 dBC at a distance of 12 feet. The wooden face of the panel was opened up in 2.07 minutes and then a 10-pound sledgehammer was used to break out the exposed 2" X 4" stud in 0.34 minute to provide clear access to the inner reinforcing layers of the panel. Then the rectangular 9" X 11" opening shown in figure 74 was cut with the 12" abrasive wheel saw. This produced acoustical and vibrational disturbances of the type shown in figures 75 and 76, respectively. The opening was completed in 7.46 minutes working time and 8.03 minutes elapsed time.

Because the abrasive wheel saw had seemed to be a little less effective than had been expected, three additional test cuts were made, each for a nominal length of 12 inches. One used the concrete cutting disk and required 0.89 minute; the other two were made using a metal cutting disk and took 0.96 and 0.85 minutes,respectively. This gave an average cutting rate of 4.66 seconds per inch. Based on these data, it was concluded that the interior reinforcing layers could have been cut in 3.6 minutes which would have given a total working time for Test 9M of only 6.01 minutes.

5.9.2 Test 9N

An electric saw equipped with a 7-1/4" carbide-tipped blade was used to make an oversize opening through the bevel siding and planking on the outside of the panel. This saw was not powerful enough for a very fast attack, but was used here because of its widespread availability.

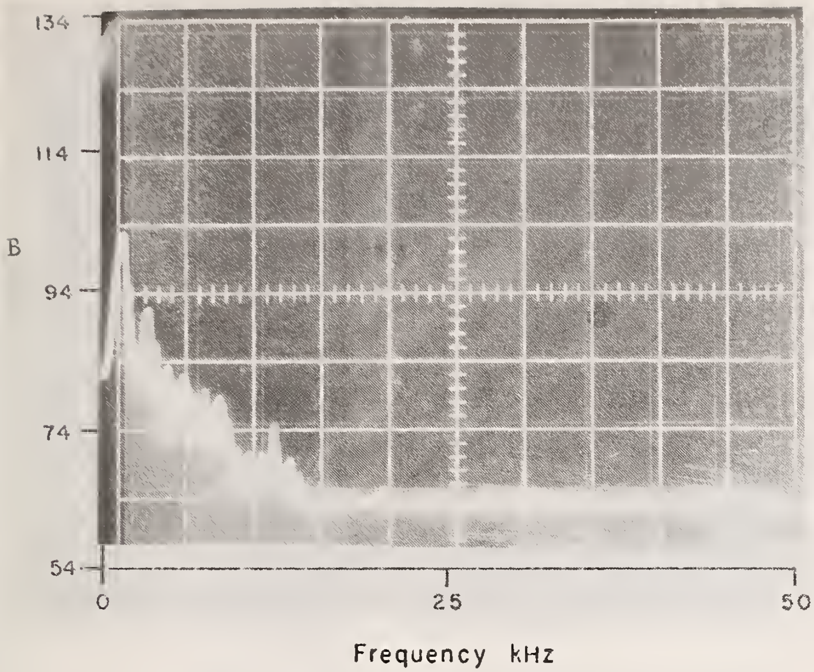


Figure 77. Acoustical Disturbances
Produced by Saw; Test 9N

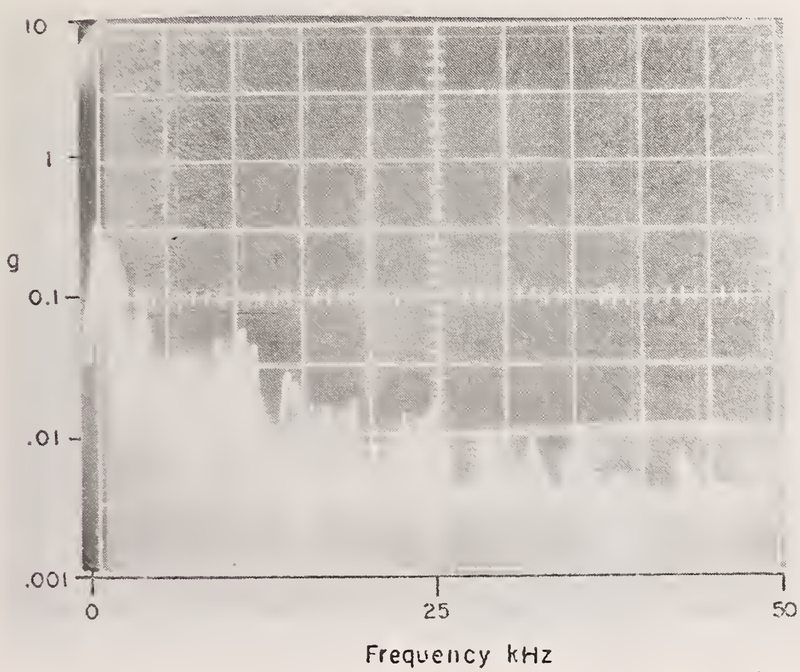


Figure 78. Vibrational Disturbances
Produced by Saw; Test 9N

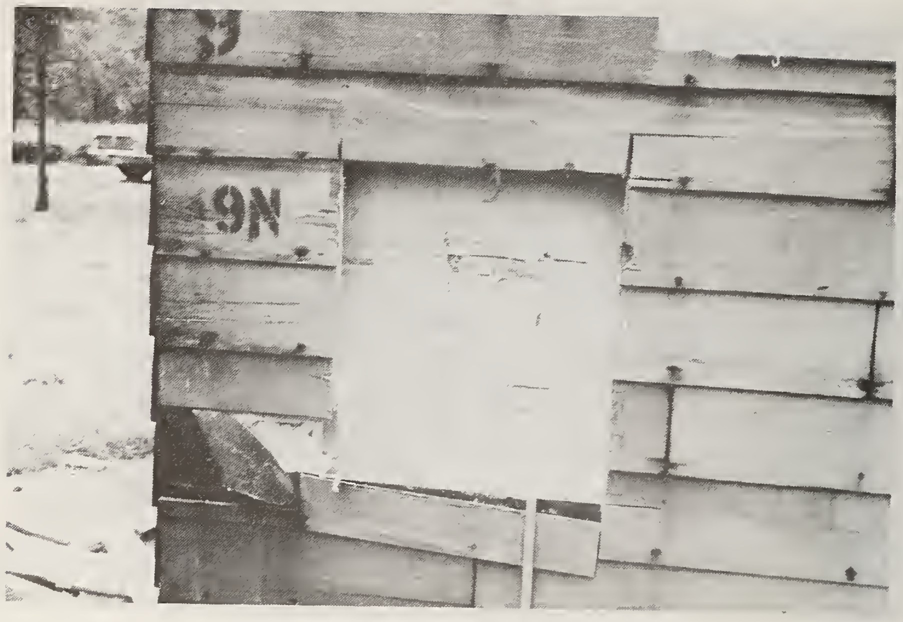


Figure 79. Test 9N in Process

Figure 80. Test 9N. Completed Opening

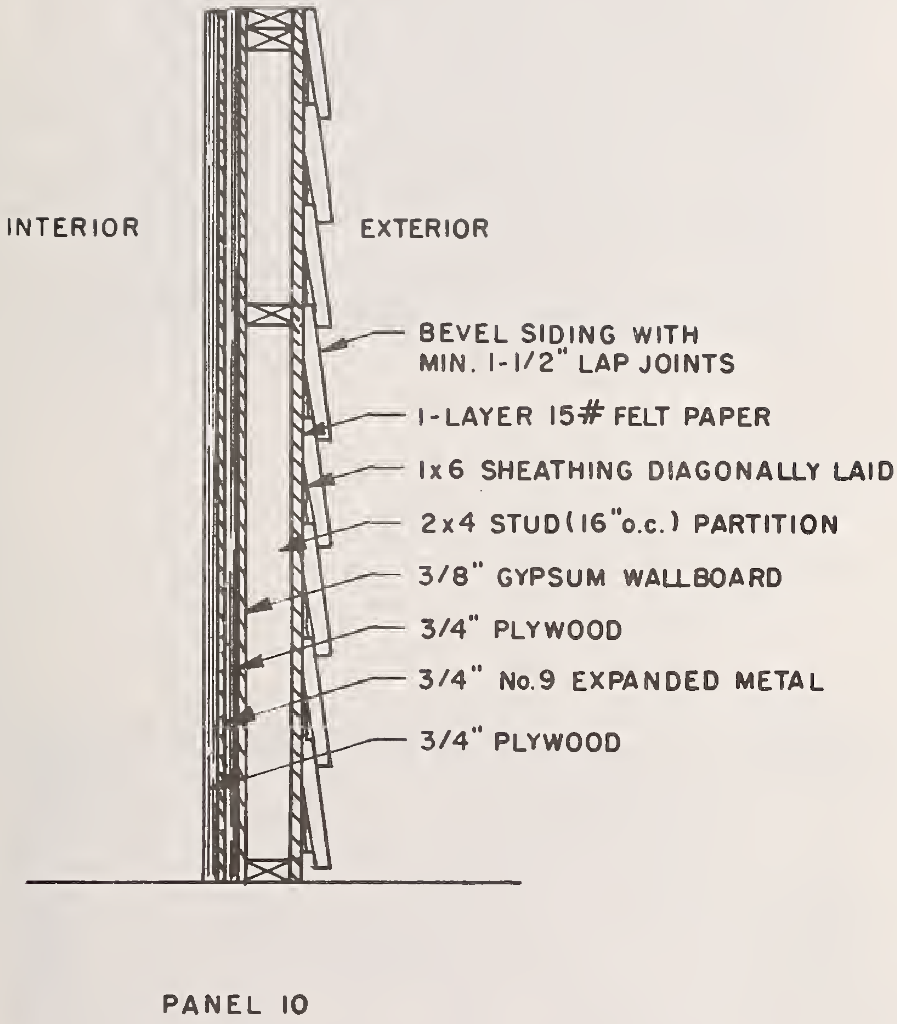


Figure 81. Construction of Panel 10

It produced SPL readings of only 82 dBC at 12' and acoustical and vibrational disturbances as shown in figures 77 and 78, respectively. Sawing occupied 2.62 minutes working time and then 3.10 minutes were spent with crowbar and sledgehammer clearing the sheathing away, knocking out a 2" X 4" stud and flattening the annular ring nails with which the inner reinforcing layers had been attached to it. A 1/2" electric drill with 3/4" bit was employed for 0.75 minute in an unsuccessful attempt to make a hole through the inner plasterboard, plywood and steel reinforcing so that a saber saw attack could be started. The attempt was unsuccessful because the bit was too large. A small pilot hole would have been necessary but no smaller drill bits were conveniently at hand so the attack switched back to the electric handsaw. It was adjusted for a depth of cut equal to the thickness of the plasterboard and plywood and a rectangular outline was cut as shown in figure 79. The bent over nails prevented a constant depth of cut from being attained and the plywood plug could not be pried out of the opening.

Since these rather ineffective attack methods had now consumed 7.98 minutes working time, they were not pursued further. The 12" abrasive wheel cutoff saw was brought into play and in another 1.96 minutes the penetration shown in figure 80 was completed. The total working time during this rather inefficient attack was 9.94 minutes and the elapsed time was 12.10 minutes.

5.10 Panel 10

The construction of Panel 10 is shown in figure 81. It is quite similar to Panel 9, differing mainly in the details of the inner reinforcing layers where 3/4" No. 9 gage expanded metal is sandwiched between two layers of 3/4" plywood.

5.10.1 Test 10N

With two operators handling the 50-pound battering ram, the outer planking and siding was smashed through by 33 blows delivered in 0.75 minute with vibrational disturbances as shown in figure 82 and with SPL readings of 97 dBC at 12'. The 10-pound sledge was then used to break out the 2" X 4" stud that was exposed by the ram. This required 20 blows and 0.55 minute. The 6-pound cutting maul was then used for 25 blows and 0.66 minute to clear away some of the shattered remnants of

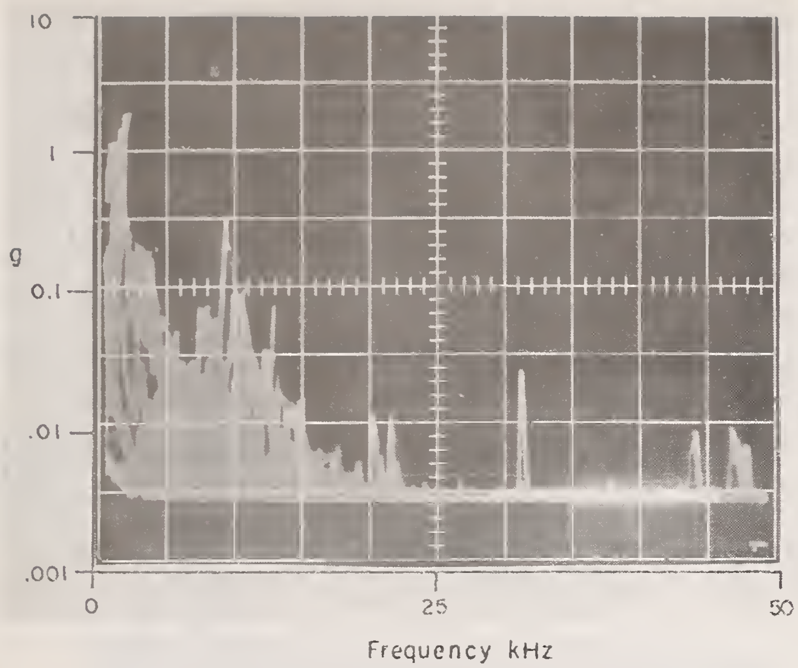


Figure 82. Vibration Disturbances Produced by Battering Ram Attacks; Test 10N

Figure 83. Test 10N. Completed Opening

the exterior planking to provide access for the battering ram to be used against the inner reinforcing liner. Then the attack with the battering ram was resumed. The inner liner was somewhat resilient however and appeared to bounce the ram back into the operators without sustaining more than modest damage. After 10 blows and 0.18 minute working time, the ram attack was abandoned and replaced by the 6-pound cutting maul. The initial breakthrough occurred after 57 blows with total accumulated working time of 3.65 minutes. An additional 114 blows cut through the plywood and expanded metal, (see fig. 83) producing an opening 14-1/2" X 9". Typical SPL readings of 96 dBC were observed during this portion of the attack which also developed vibrational disturbances as shown in figure 84.

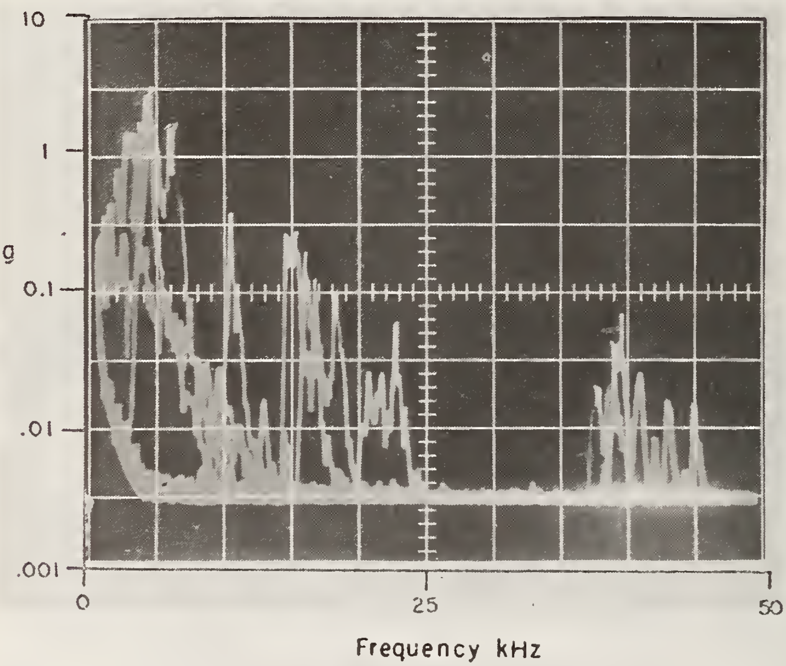
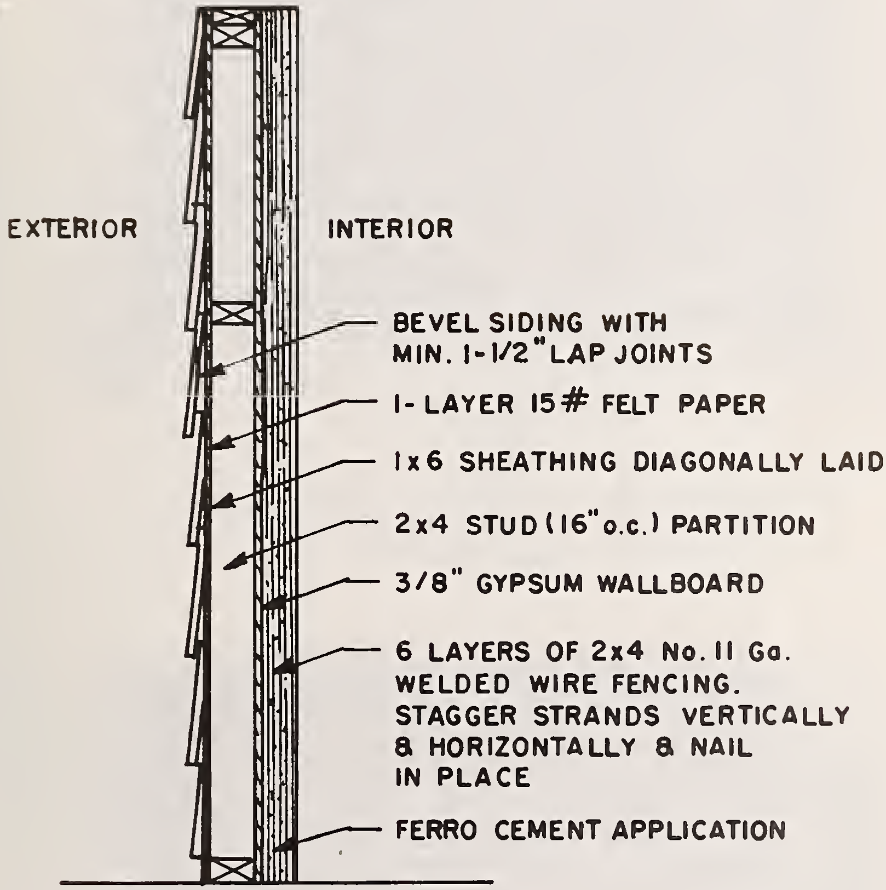


Figure 84. Vibrational Disturbances Produced by Cutting Maul; Test 10N



PANEL 11

Figure 85. Construction of Panel 11

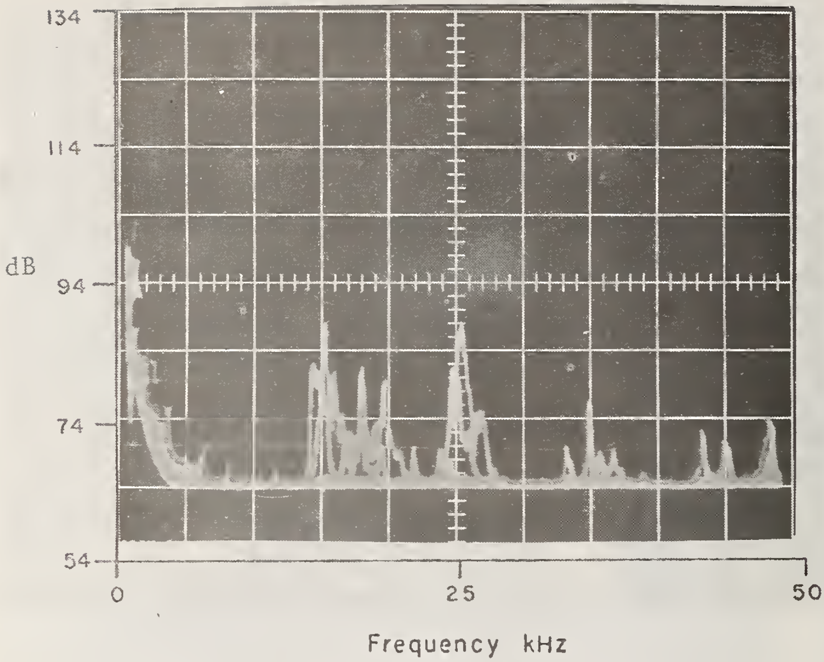


Figure 86. Acoustical Disturbances Produced by Cutting Maul; Test 11U

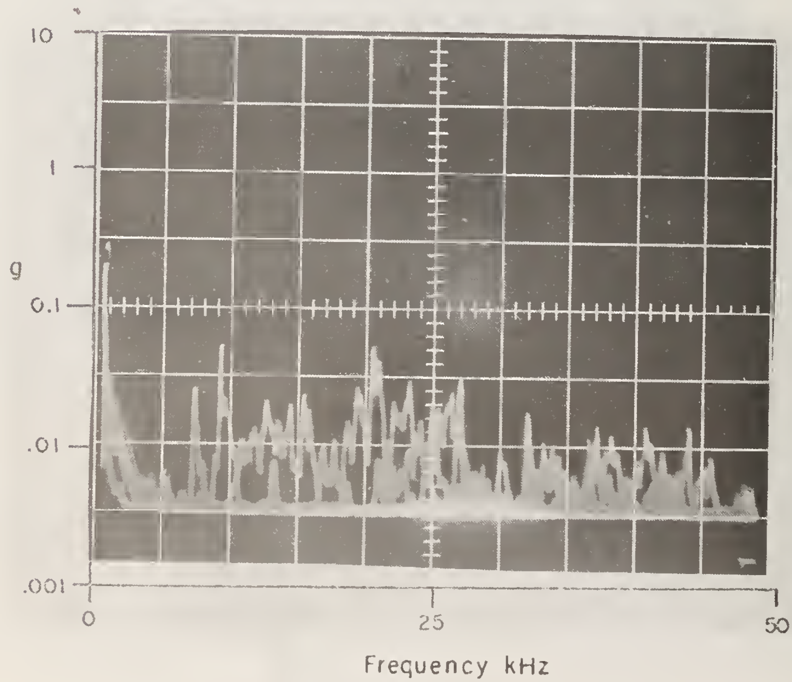


Figure 87. Vibrational Disturbances Produced by Cutting Maul; Test 11U

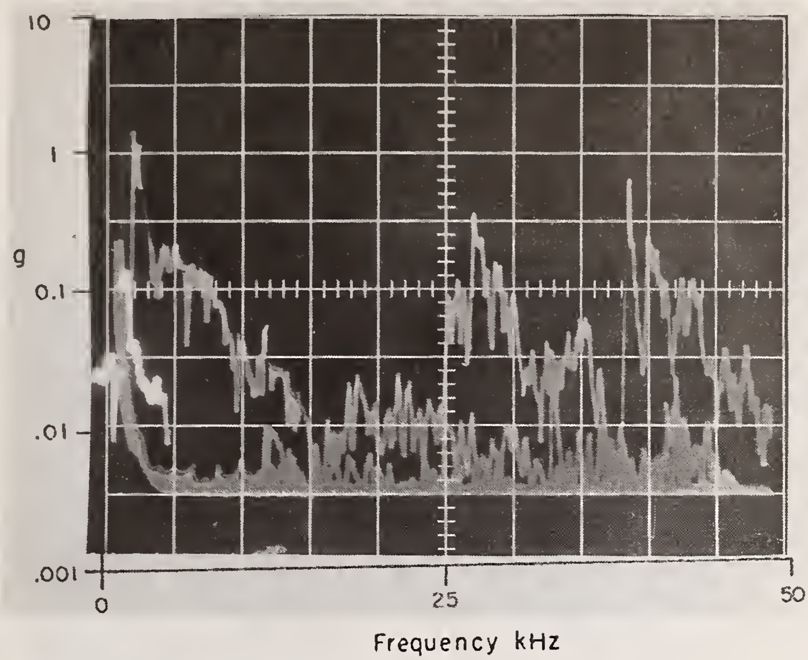


Figure 88. Vibrational Disturbances Produced by Sledgehammer; Test 11U

Figure 89. Test 11U. Ferro-cement Reinforcing Wire Exposed

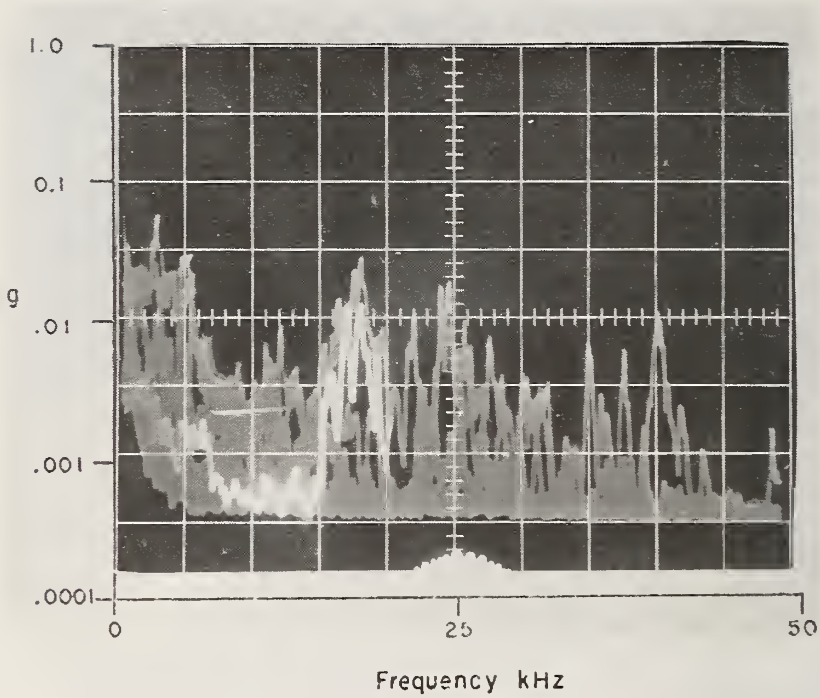


Figure 90. Multiple Sweep Recording of Vibrational Disturbances Resulting from Bolt Cutter Attacks; Test 11U

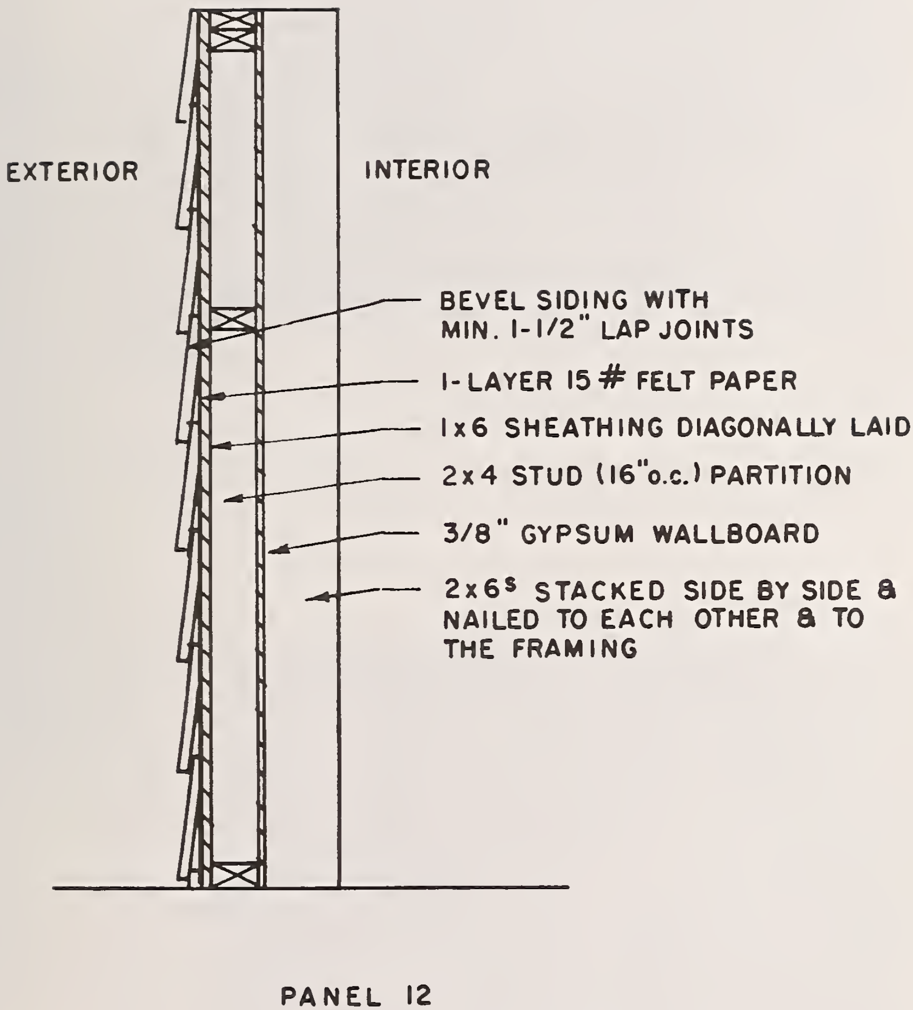


Figure 91. Construction of Panel 12

This penetration required a total of 6.73 minutes working time and 8.0 minutes elapsed time.

5.11 Panel 11

The constructon of Panel 11 is shown in figure 85. it, too, is similar to Panel 9 except for the inner reinforcing which was ferro-cement in this experiment.

5.11.1 Test 11U

In this test, the 6-pound cutting maul was used to break through the exterior siding and planking with 43 blows. Acoustical and vibrational disturbance samples are shown in figures 86 and 87, respectively. Then the 10-pound sledgehammer was used to break off the exposed 2" X 4" wooden stud and to attack the ferro-cement liner. After 113 blows which produced vibrational disturbances as shown in figure 88, the concrete was spalled clear of the reinforcing wire. This produced SPL readings of 94 to 98 dBC at a distance of 12'. At this point a total working time of 4.71 minutes had been used and the opening was as shown in figure 89 where the ferro-cement reinforcing wires are about to be cut with 3/8" bolt cutters. This took an additional 2.12 minutes and produced vibrational disturbances as shown in the multiple-sweep recording in figure 90. The acoustical disturbances from the bolt cutters were only slightly above ambient levels. The final opening was an oval-shaped aperture with dimensions of approximately 12" X 15". It required 6.83 minutes working time and 7.05 minutes elapsed time to complete.

5.12 Panel 12

The construction of Panel 12 is shown in figure 91. It, too, was similar to Panel 9 except for the interior reinforcing which consisted of stacked 2" X 6" timbers nailed to each other during stacking.

5.12.1 Test 12U

Since the cutting maul appeared to be reasonably effective in penetrating the exterior siding and sheathing in some of the preceding tests, it was employed here for 40 blows, followed by 28 blows from the 10-pound sledge to break out the exposed 2" X 4" stud. This exposed the interior liner in 1.96 minutes working time. The acoustical and vibrational disturbances were similar to those produced in penetrating the exterior of Panels 9, 10 and 11.

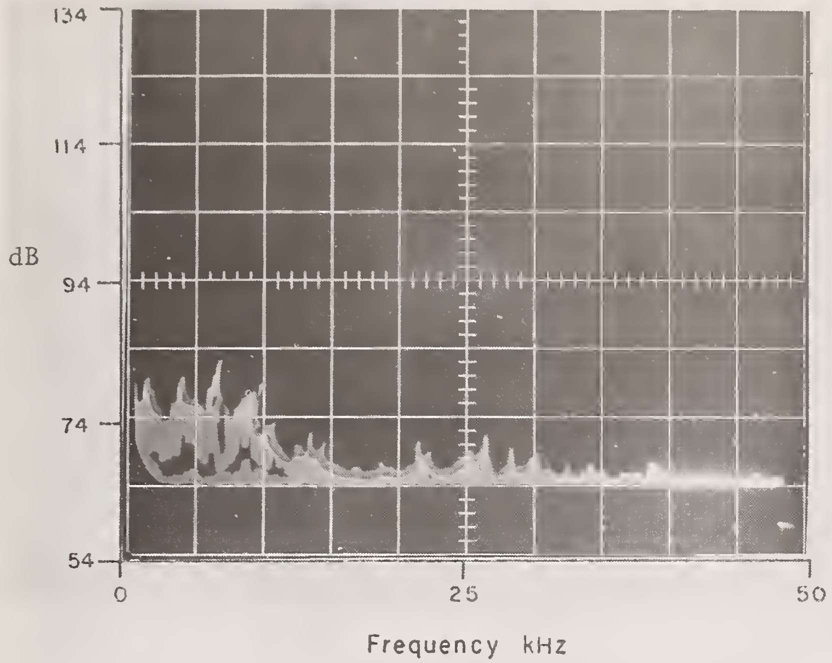


Figure 92. Multiple Sweep Trace of Acoustical Disturbances from Electric Drill; Test 12U

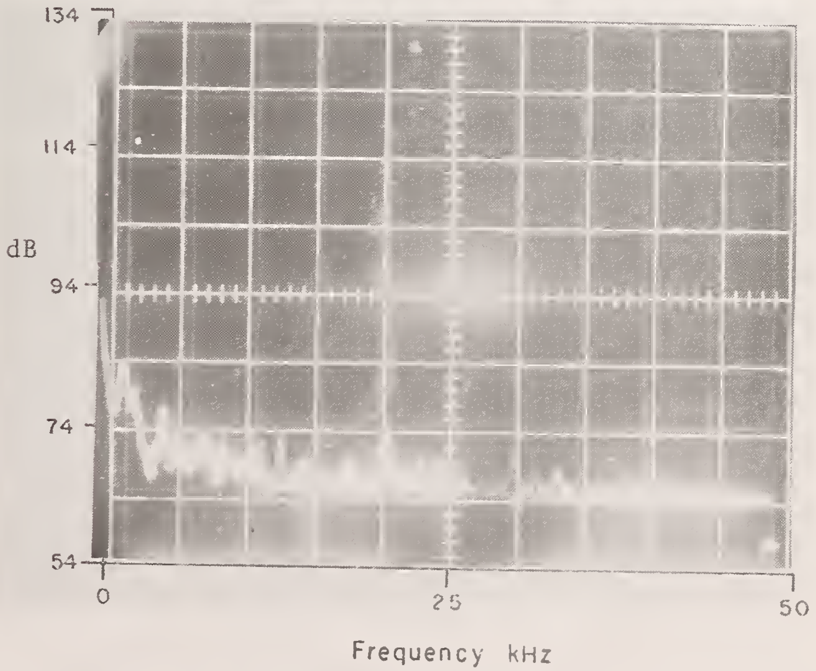


Figure 93. Typical Acoustical Disturbances Produced by the Saber Saw; Test 12U

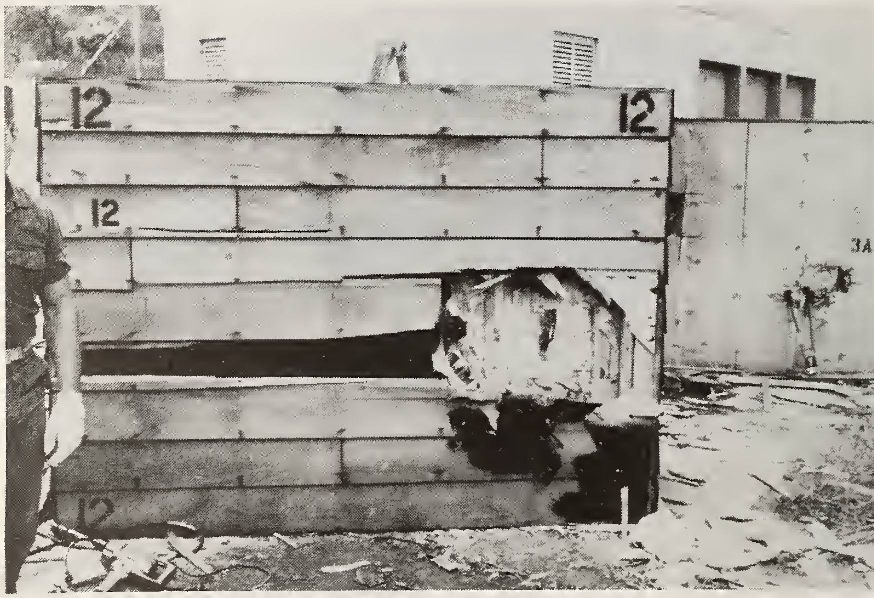


Figure 94. Test 12U. Final Opening

Next, a 1/2" electric drill with a 5/8" drill bit was used to make two holes through the 2" X 6" reinforcing timbers at diagonally opposite corners of an 8" X 12" target rectangle. This required 1.39 minutes and produced SPL readings of 74 to 78 dB as observed at a distance of 12'. A multiple-sweep trace of the spectrum is shown in figure 92. These two holes were used as the starting points for two horizontal cuts which were made with a saber saw equipped with a 6" long blade having 5 teeth per inch. Each cut was approximately 9-1/2" long and the working time for both was 4.58 minutes. The average cutting rate through the 5-5/8" actual thickness of the stacked 2" X 6" timbers was 14.46 seconds per lineal inch. Typical acoustical disturbances produced by the saber saw are shown in figure 93.

Then, the sledgehammer, crowbar and 26-pound bar were used for 3.58 minutes to clear the plug out of the opening in which it was held by the nails driven into it from the adjoining 2" X 6" timbers. The final opening shown in figure 94 measured only 9-1/2" X 10" and lacked having the requisite area by one square inch. It took 12.13 minutes working time and 17.19 minutes elapsed time. A part of the elapsed time was used in replacing two broken blades in the saber saw which was really too small for this attack. Therefore, another penetration was made in Panel 12 using more sophisticated attack tooling. Because of its impromptu nature, it was identified simply as Test 12.

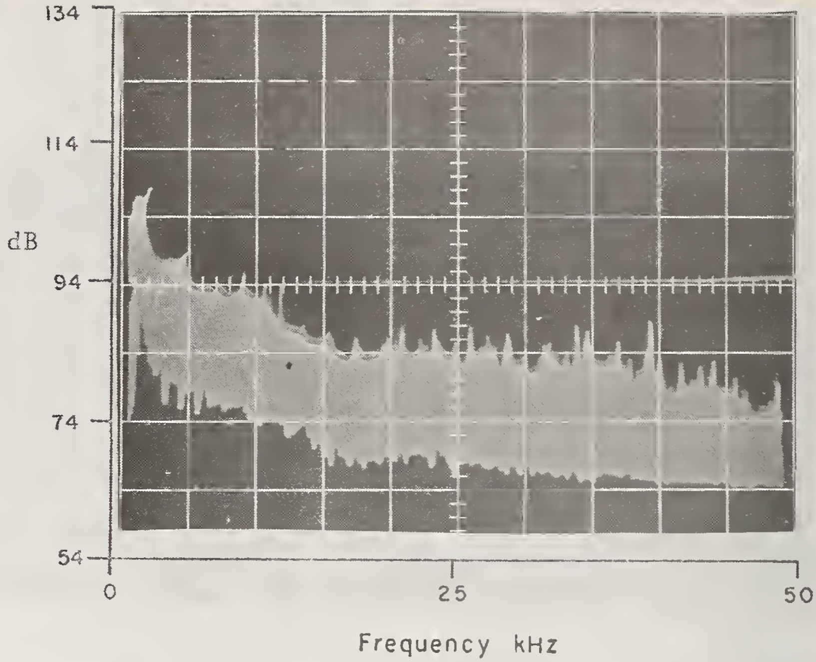


Figure 95. Multiple Sweep Traces of Acoustical Disturbances Produced by Hubless Saw; Test 12

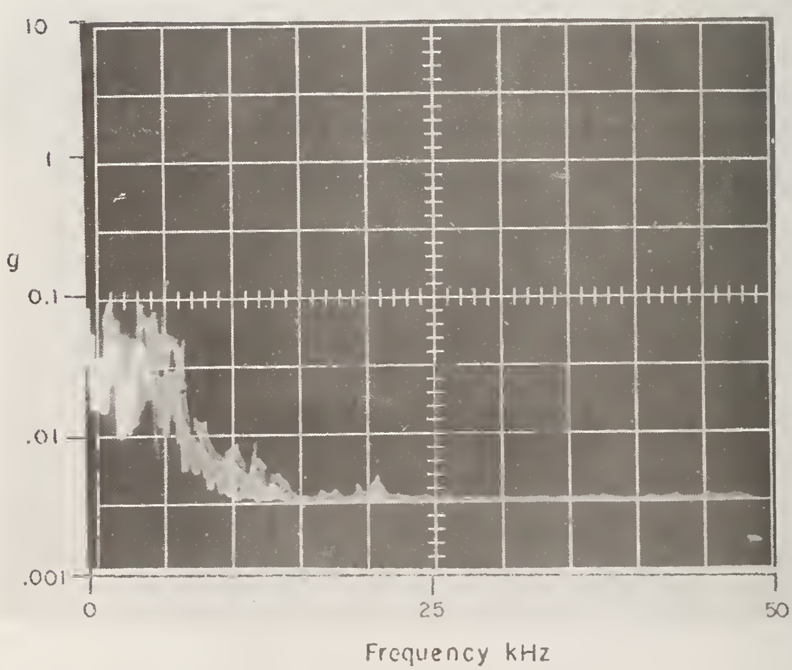


Figure 96. Multiple Sweep Traces of Vibrational Disturbances Produced by Hubless Saw; Test 12

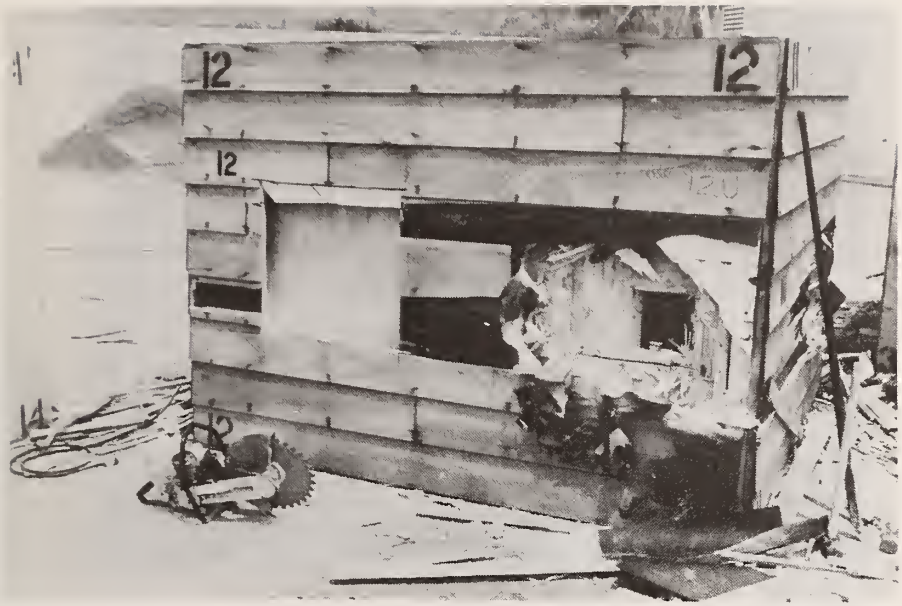


Figure 97. Panel 12, Siding and Sheathing Cut; Test 12

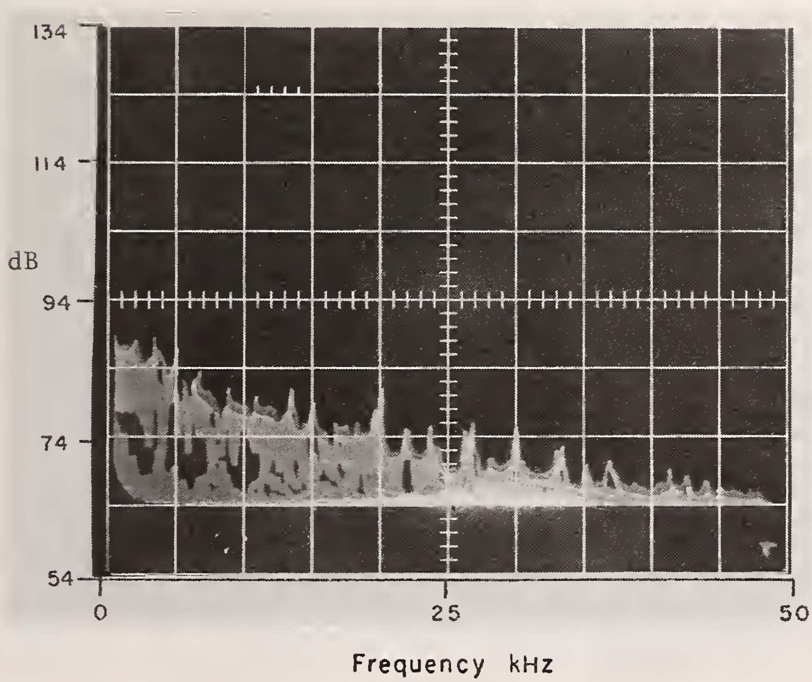


Figure 98. Acoustical Disturbances Produced by Attacks from 14" Hubbed Power Saw; Test 12

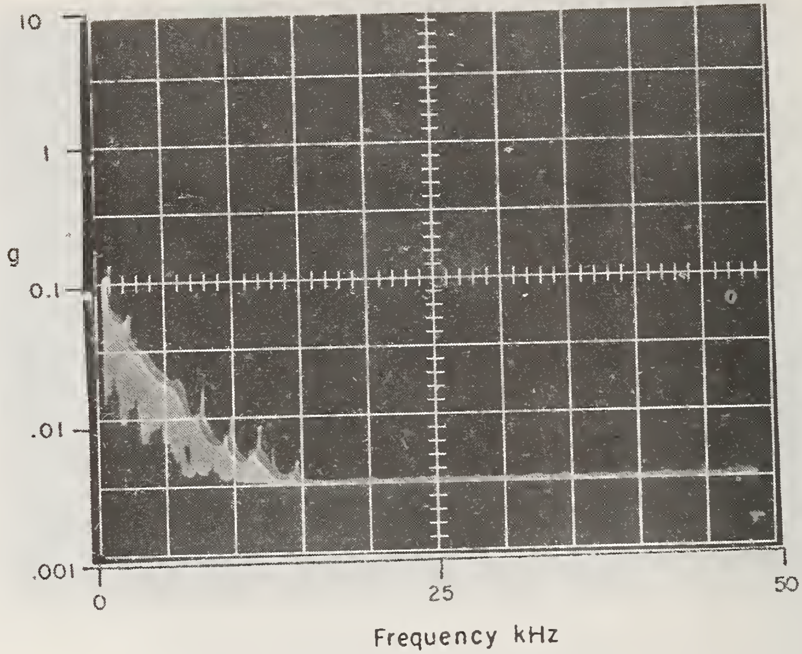


Figure 99. Vibrational Disturbances Produced by Attacks from 14" Hubbed Power Saw; Test 12

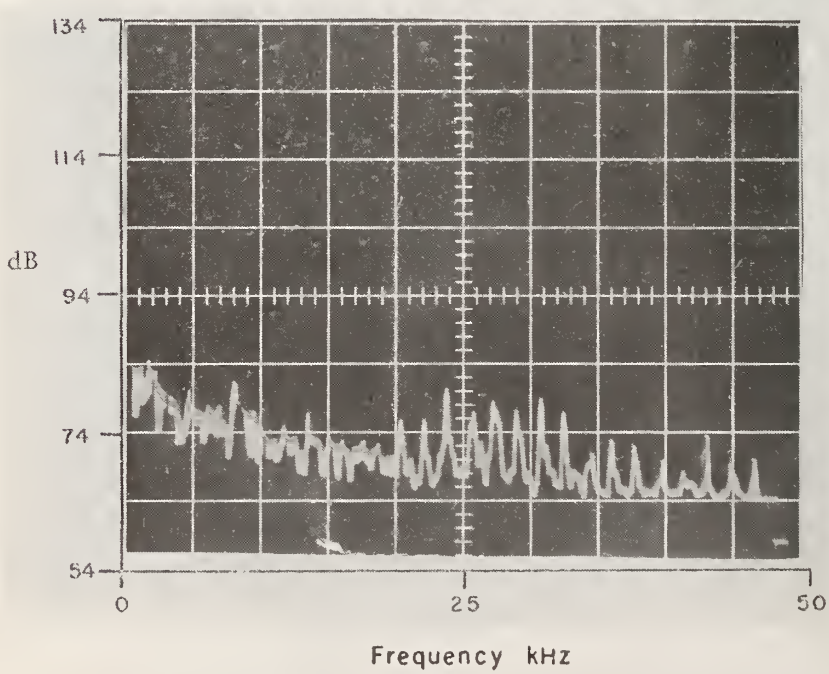


Figure 100. Acoustical Disturbances Produced by Attacks from 14" Hubbed Power Saw; Test 12

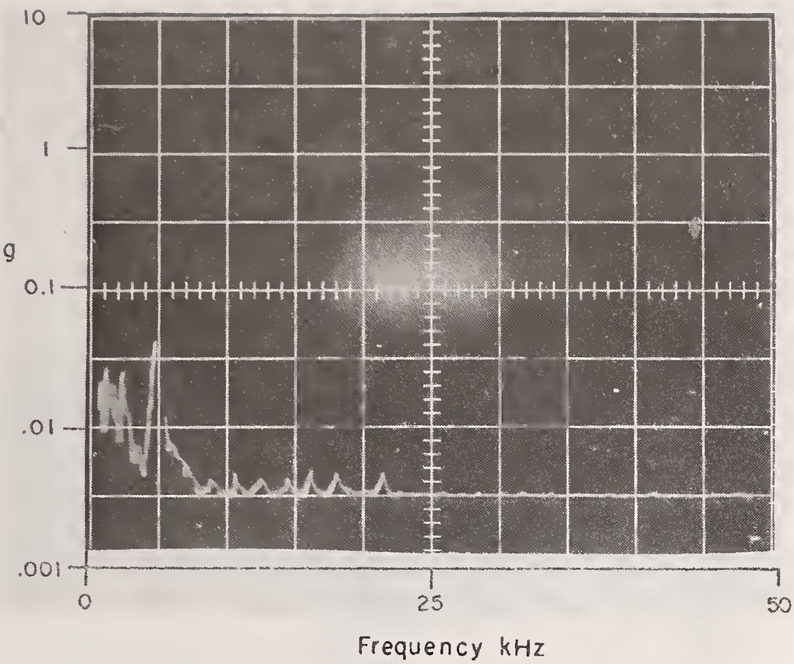


Figure 101. Vibrational Disturbances Produced by Attacks from 14" Center-Hubbed Saw; Test 12

Figure 102. Cutting with Hubless Saw; Test 12

5.12.2 Test 12

The 14" gasoline-powered hubless saw had been intended for use against Panel 12 because it could be used for making cuts to depths of at least 10". The blade of this saw had been damaged in an earlier test when all but five of the carbide tips of the teeth had been broken off. In this damaged condition, it could not be expected to cut with normal speed and efficiency; nevertheless, a test cut was made. The cut was 29" long and 10" deep and, since it was made from the outside of the panel, approximately 3-5/8" of the depth of the cut was through the air space formed by the thickness of the 2" X 4" studs supporting the outer sheathing of the panel. The time required for this test cut was 3.66 minutes, giving an average cutting rate of 5.52 seconds per lineal inch. Multiple sweep traces of the acoustical and vibrational disturbances produced during this test cut are shown in figures 95 and 96, respectively.

Because of the uncertainty as to the extent that the performance of this saw was degraded by the blade damage, it was decided to use a different 14" center-hubbed, gasoline-powered saw to cut through the outer sheathing making an oversize hole and then to make two parallel horizontal cuts in the stacked 2" X 6" timbers to the depth permitted by hub clearance. Then the depth of these latter two cuts would be extended through the 2" X 6" timbers using the damaged hubless saw. It was hoped that this strategem would minimize the influence of the damaged blade on the total cutting time.

The outer siding and sheathing was cut off and removed in 1.44 minutes as shown in figure 97. It produced the acoustical and vibrational disturbances shown in figures 98 and 99, respectively. Then two horizontal cuts approximately 13" long were made, one above the other and 18" apart, to a depth of about 4" into the 2" X 6" timbers. These required 1.73 minutes working time and produced the acoustical and vibrational disturbances shown in figures 100 and 101, respectively.

The hubless saw was then used for 2.51 minutes to extend the depth of the two horizontal cuts completely through the panel reinforcing as shown in figure 102.

The nailed timbers in the remaining plug were driven out with the 10-pound sledgehammer in 46 blows delivered in 1.11 minutes. The resulting opening shown in figure 103 measured 13" X 18" and was produced in 6.79 minutes working time and 9.70 minutes elapsed time. It is estimated that both of these times could have been reduced at least a minute if a replacement blade for the hubless saw had been available.

Figure 103. Completed Opening;
Test 12

5.12.3 <u>Test 12Q</u>

A single hole was drilled through the 5-5/8" thickness of one of the 2" X 6" reinforcing timbers using a 1/2" electric drill and a 1-1/2" flat blade, wood bit. The time required was 1.16 minutes giving an average drilling rate of 12.3 seconds per inch. The acoustical and vibrational disturbances which were produced are shown in figures 104 and 105, respectively.

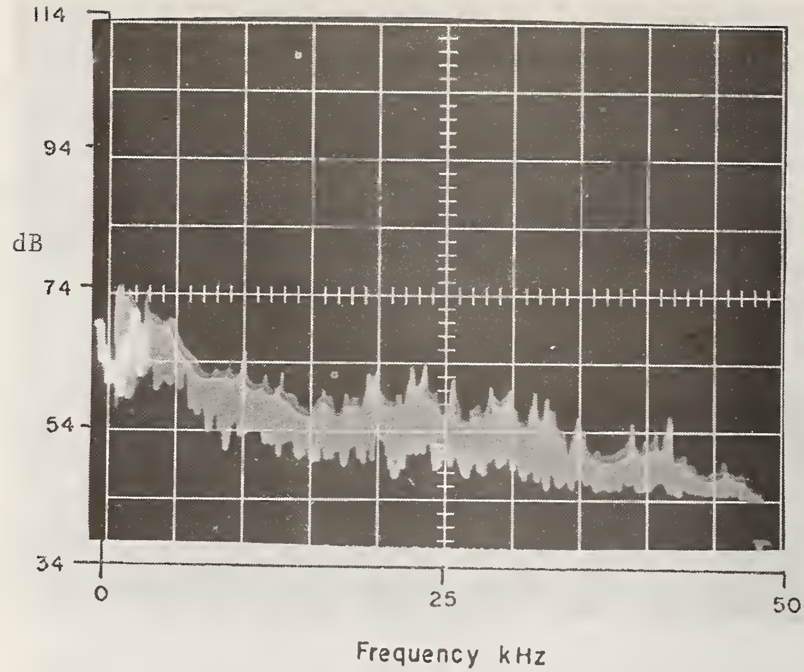


Figure 104. Acoustical Disturbances Produced by Drill and Wood Bit; Test 12Q

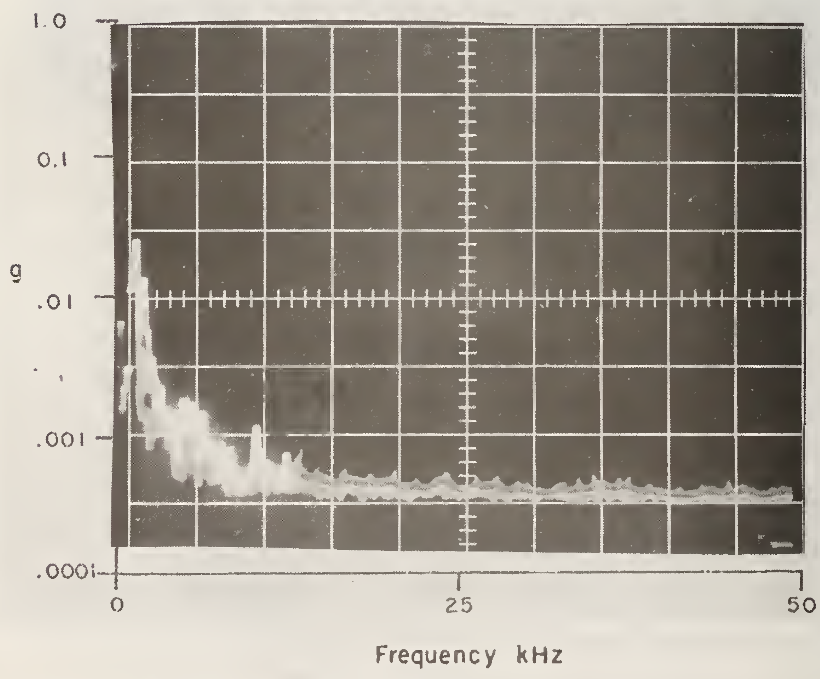


Figure 105. Vibrational Disturbances Produced by Drill and Wood Bit; Test 12Q

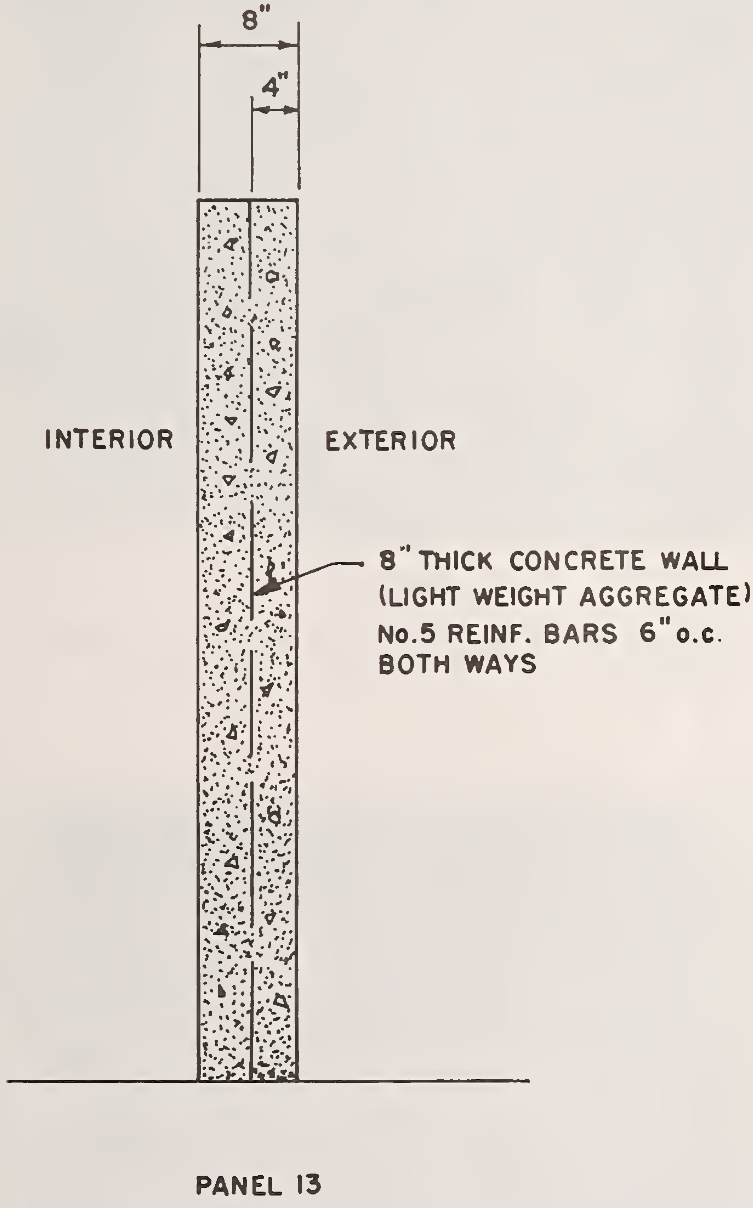


Figure 106. Construction of Panel 13

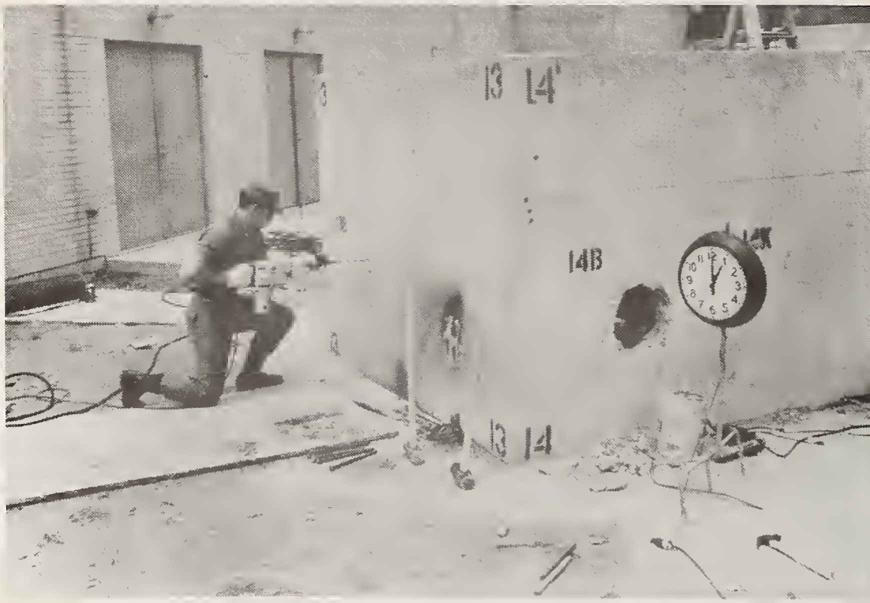


Figure 107. Test 13B. Rotohammer Drilling

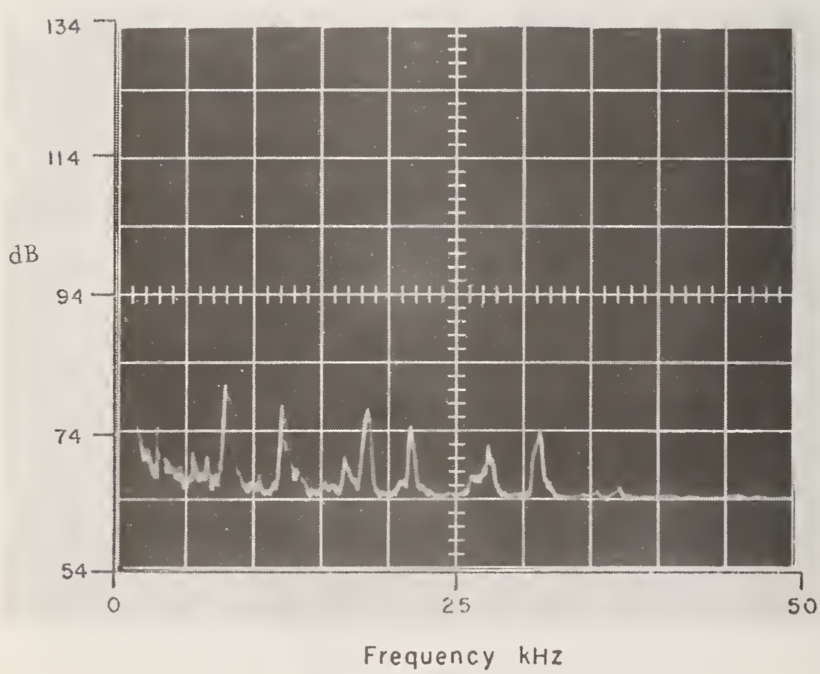


Figure 108. Acoustical Disturbances Produced by Rotohammer and Drill; Test 13B

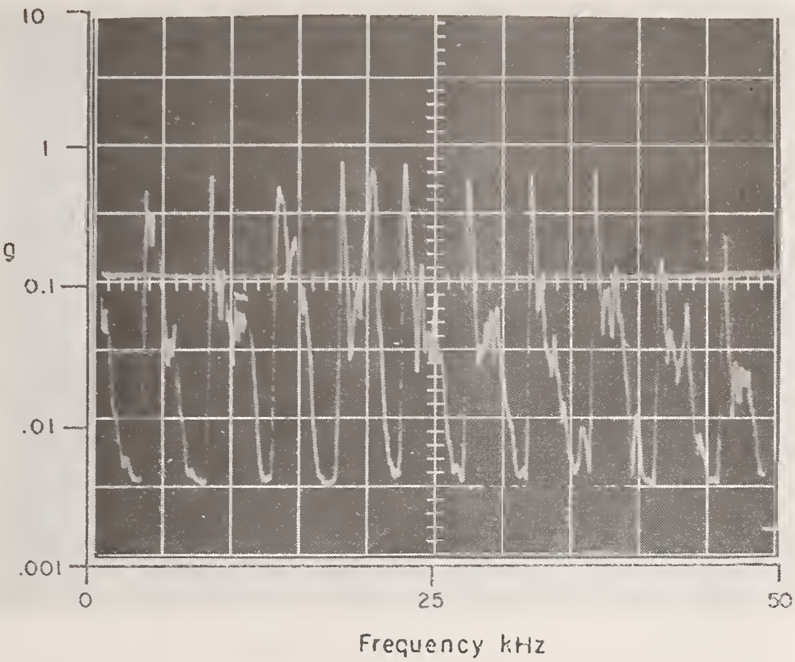


Figure 109. Vibrational Disturbances Produced by Rotohammer and Drill; Test 13B

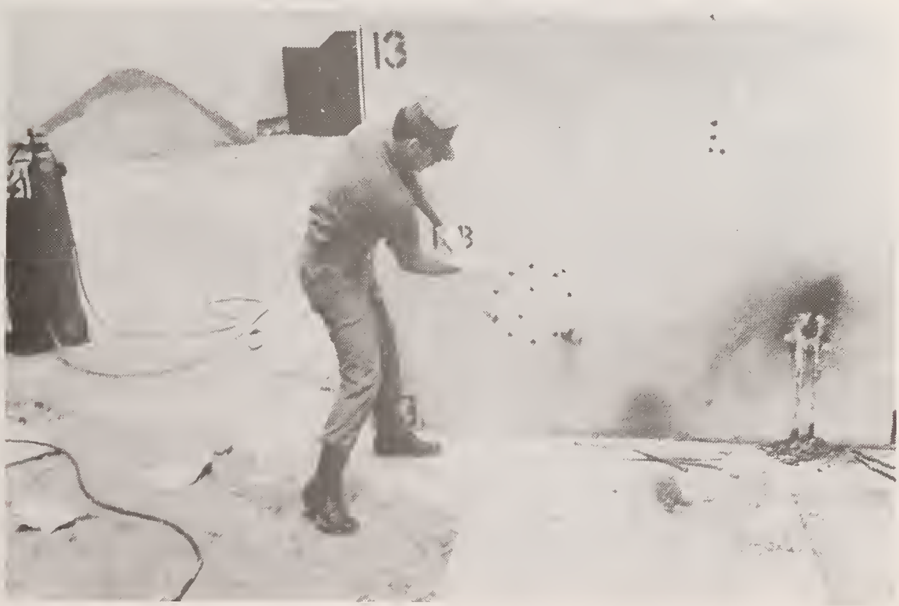


Figure 110. Spalling Activity in Progress; Test 13B

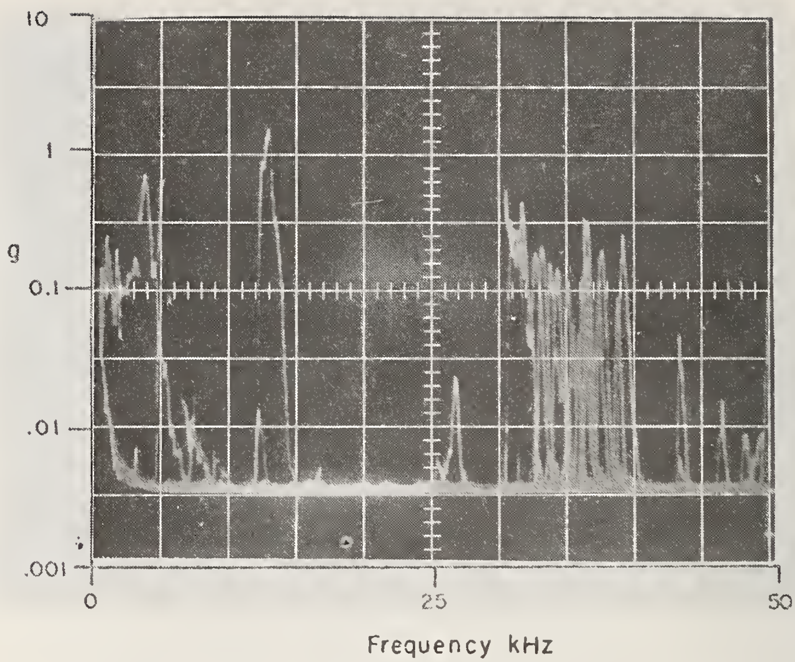


Figure 111. Vibrational Disturbances Produced by Spalling Activity; Test 13B

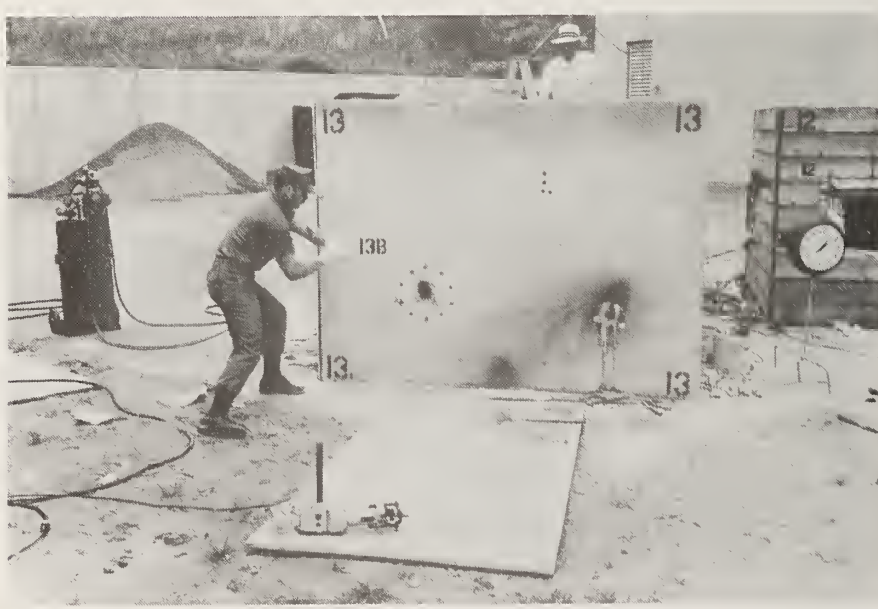


Figure 112. Enlarged Center Breakthrough; Test 13B

5.13 Panel 13

The construction of Panel 13 is shown in figure 106. The concrete used in constructing this panel was formulated with a lightweight aggregate and weighed approximately 120 pounds per cubic foot as contrasted to the nominal 144 pounds for regular concrete.

5.13.1 Test 13B

As shown in figure 107, the rotohammer and 3/4" drill was used to drill five holes to a depth of 5" at equally spaced positions around the circumference of a 12" diameter target circle. A sixth hole was drilled to the same depth at the center of the circle. Then five more holes were drilled to a depth of 3" along the circumference at points midway between the 5" deep holes. Finally, three more holes were drilled 3" deep at 120-degree intervals around a smaller concentric 5-1/2" diameter circle. The 54 linear inches of drilling required 2.16 minutes of working time for an average rate of 2.4 seconds per inch. Samples of the acoustical and vibrational disturbances which were produced are shown in figures 108 and 109, respectively.

Next, using a 3/4" bull point punch and 10-pound sledgehammer, the concrete was spalled from the bottoms of the drilled holes. It was intended that the 5" deep holes be spalled first, followed by the 3" deep holes; however, due to a mix-up, this procedure was not followed and the holes were spalled out sequentially without regard to their depth. In spite of this, the operation proceeded rapidly and was completed in 2.74 minutes working time and 104 sledgehammer blows. Figure 110 shows the spalling activity in progress. Typical vibrational disturbances are shown in figure 111. SPL readings of 92 dBC were observed at a distance of 12'.

Then, the center of the target area was attacked with the 10-pound sledgehammer. The initial penetration occurred after 35 blows and then, as shown in figure 112, another 23 blows were used to enlarge the central hole to a diameter of about 6". These 58 blows were delivered in 1.43 minutes working time.

Figure 113. Test 13B Using Taper Punch to Spall from Edge of Holes into Central Opening

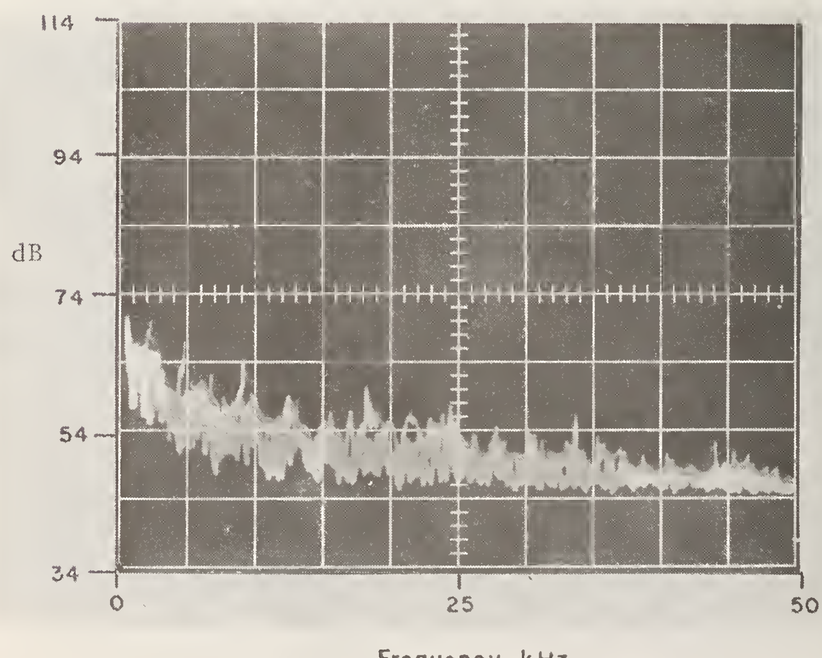


Figure 114. Acoustical Disturbances Produced by Burning Bar; Test 13B

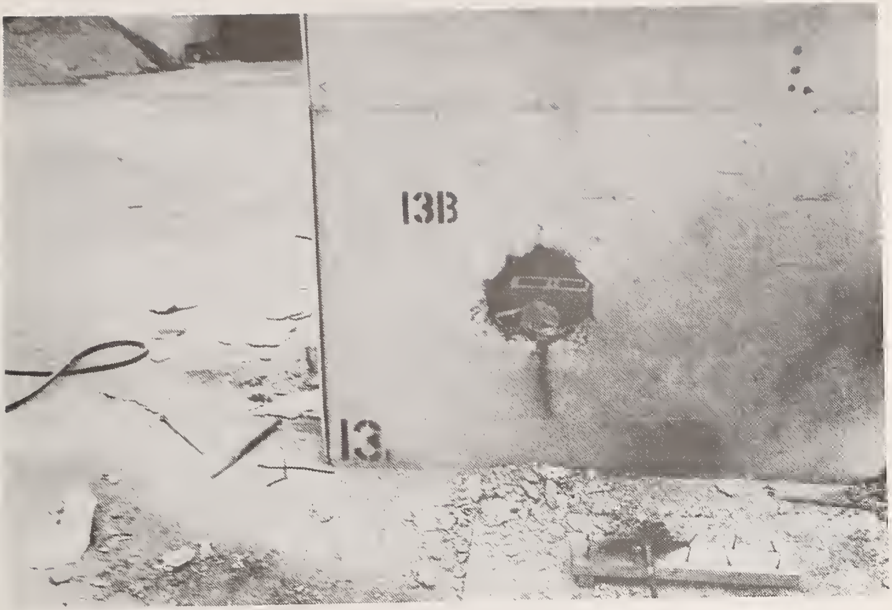


Figure 115. Test 13B. Completed Opening

Figure 116. Test 13D. Beginning of Burning Bar Attack

Figure 117. Test 13D. Continuation of Attack

Figure 118. Test 13D. Close-up of Hole Melted through the Concrete

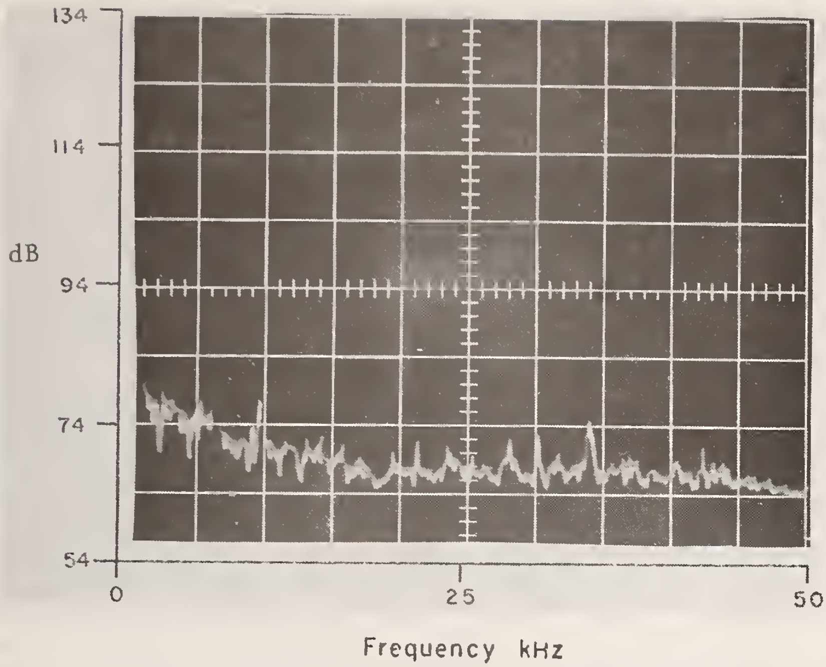


Figure 119. Test 13D. Acoustical Disturbances Produced by Burning Bar

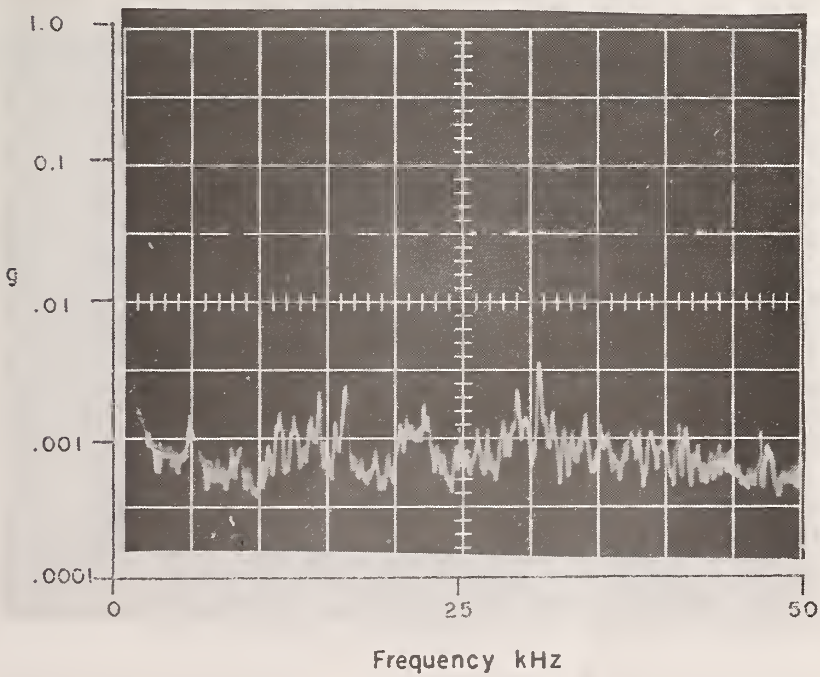


Figure 120. Test 13D. Vibrational Disturbances Produced by Burning Bar

Next, as shown in figure 113, a 1-1/4" diameter taper punch was driven into each of the circumferential holes spalling concrete into the central threakthrough area. This required 86 blows and 2.38 minutes working time. On one of the holes, spalling of the taper punch was inhibited by a reinforcing bar; this and a few other projecting knobs of concrete were knocked clear with 13 blows of the sledgehammer in 0.28 minutes.

The burning bar was then used to cut the four sections of reinforcing bar remaining in the opening. Using 75 p.s.i. oxygen pressure and 18" of bar, the eight cuts were made in 0.53 minute. The acoustical disturbances produced by the burning bar are shown in figure 114. The completed penetration is shown in figure 115. It required 9.52 minutes working time and 16.15 minutes elapsed time.

Three cuts were made through the 5/8" reinforcing rod using the oxyacetylene torch so as to estimate the time which would have been required for this penetration if the torch had been used instead of the burning bar. The average time per cut was 0.31 minute, so the use of the torch would have added an estimated 1.95 minutes to the working time.

Further time tests were made using alternative drill sizes in the rotohammer. A 7/8" diameter drill penetrated the lightweight concrete at a rate of 2.88 seconds per inch and a 1" diameter at a rate of 3.52 seconds per inch.

5.13.2 Test 13D

The burning bar was used to make a single hole through Panel 13, as shown in figures 116, 117, and 118. At 160 p.s.i. oxygen pressure, it consumed 38" of bar and required 0.78 minute working time and 1.08 minutes elapsed time. Samples of the acoustical and vibrational disturbances produced are shown in figures 119 and 120, respectively.

5.13.3 Test 13K

Using the A-frame suspension shown in figure 121, the 50-pound battering ram was used in an attack against Panel 13. For 100 blows, the ram was swung back on its suspension harness until the center of gravity had been lifted approximately 2'. Then it was released to swing, pendulum fashion, against the panel. This produced surface spalling

Figure 121. Test 13K. Battering Ram

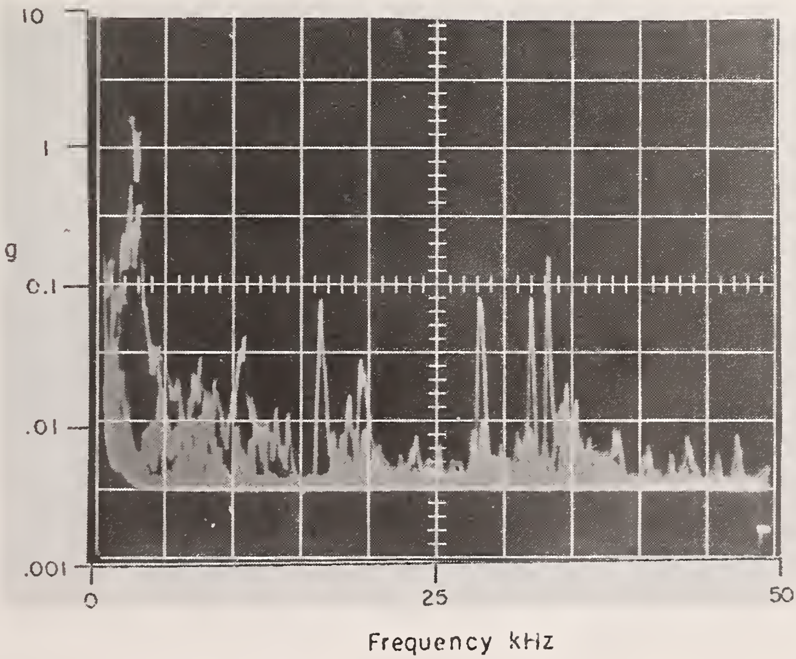


Figure 122. Test 13K. Multiple Sweep Trace of Vibrational Disturbances Resulting from Ram Attacks

Figure 123. Test 13K. Two-man Operation of Suspended Battering Ram

Figure 124. Spalling Produced by 301 Blows from Battering Ram ; Test 13K

over an area of about 6" X 7" to a maximum centel depth of 1-1/4". A multiple sweep trace of the resulting vibrational disturbances is shown in figure 122. SPL readings of 104 dBC were observed at 12'.

Then, for another 201 blows, the two-man operation shown in figure 123 was employed. Here the suspension carried the weight of the ram and the operators accelerated it to the maximum velocity they could attain and released it just before impact so as to avoid the shocks which were transmitted back through its handles. The 301 total blows produced the surface spalling shown in figure 124 which had attained a maximum depth of only 2-1/2 inches. The test was terminated at this point as 10.41 minutes of working time had already been expended and this was obviously not an effective attack technique on the reinforced concrete of this panel.

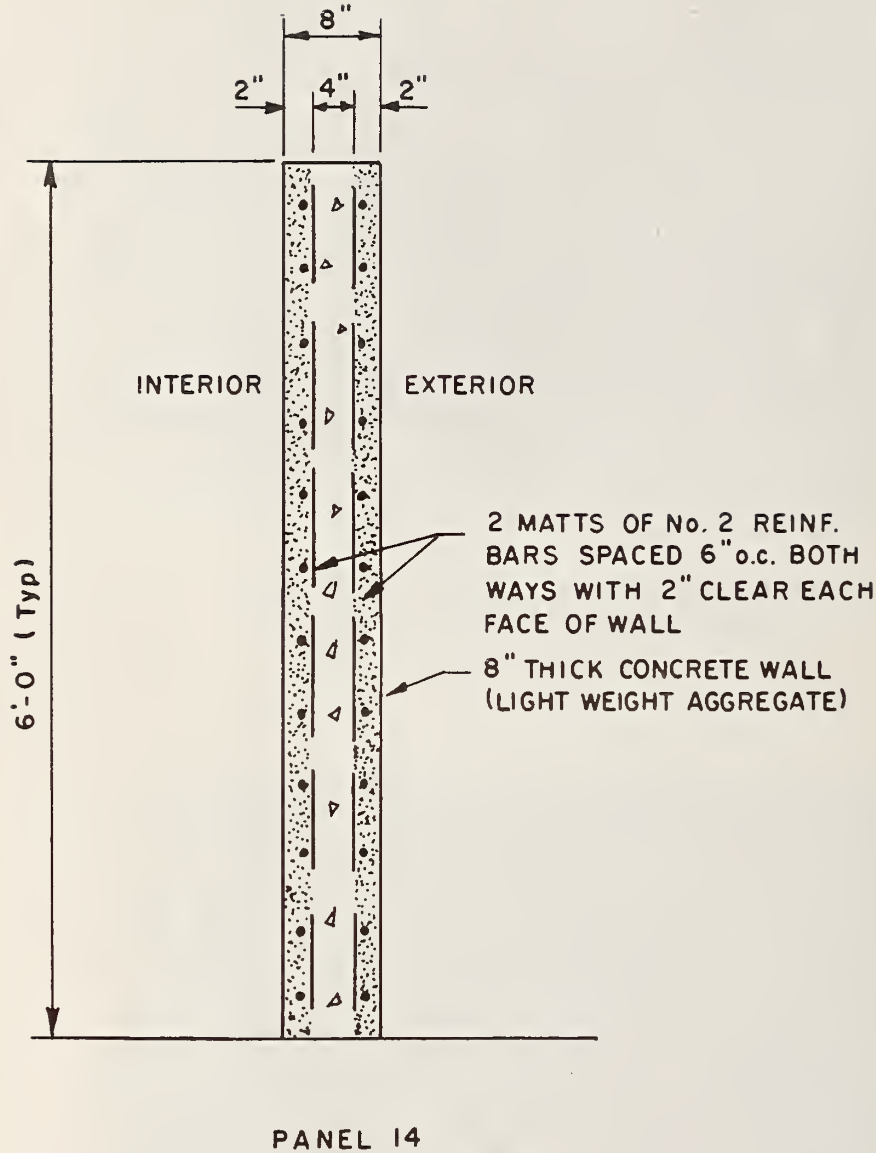


Figure 125. Construction of Panel 14

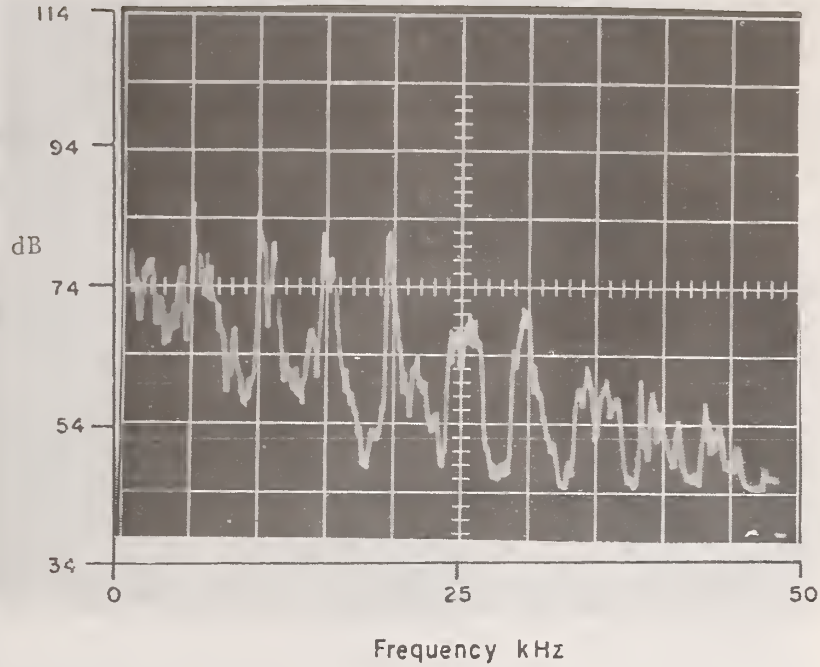


Figure 126. Test 14B. Acoustical Disturbances Produced by Rotohammer and Drill

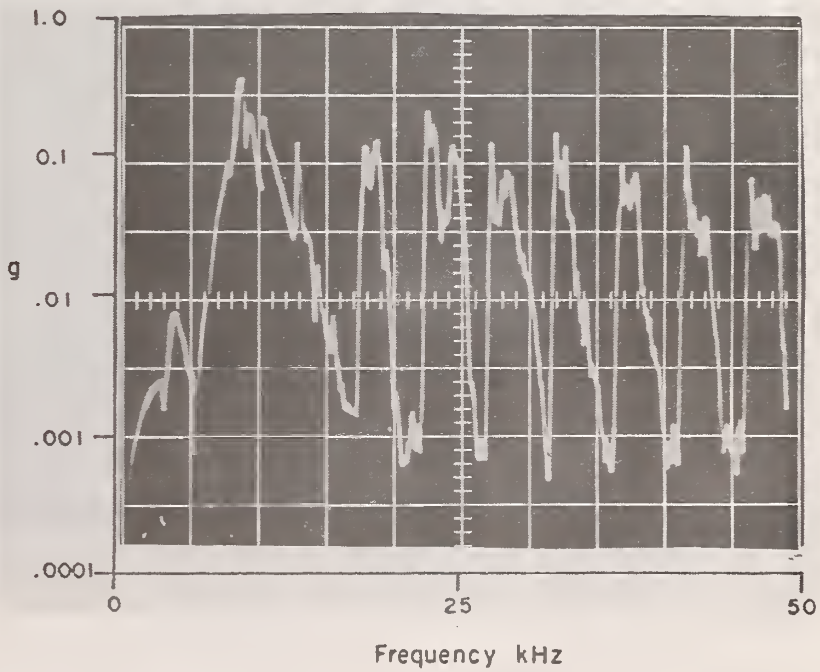


Figure 127. Vibrational Disturbances Produced by Rotohammer and Drill; Test 14B

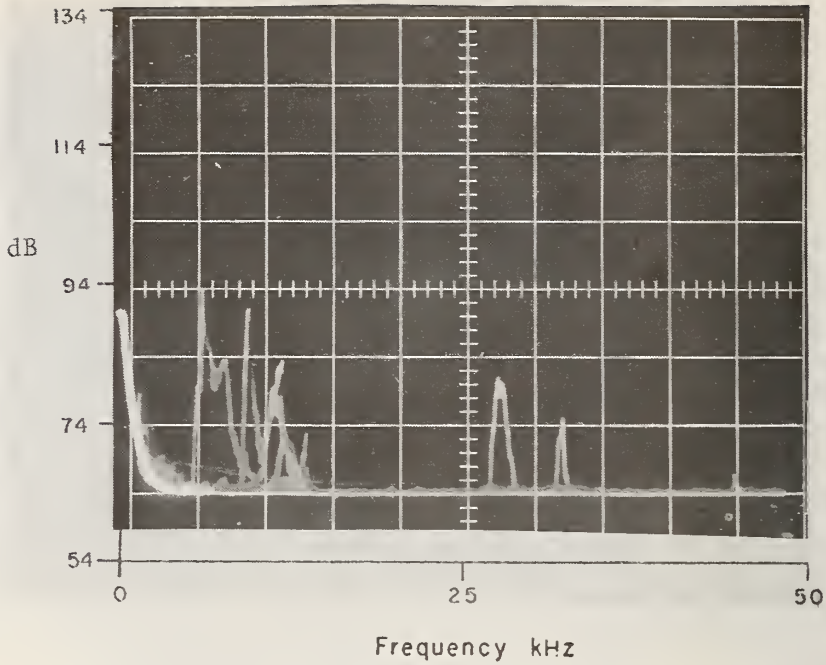


Figure 128. Multiple Sweep Traces of Acoustical Disturbances Resulting from Spalling; Test 14B

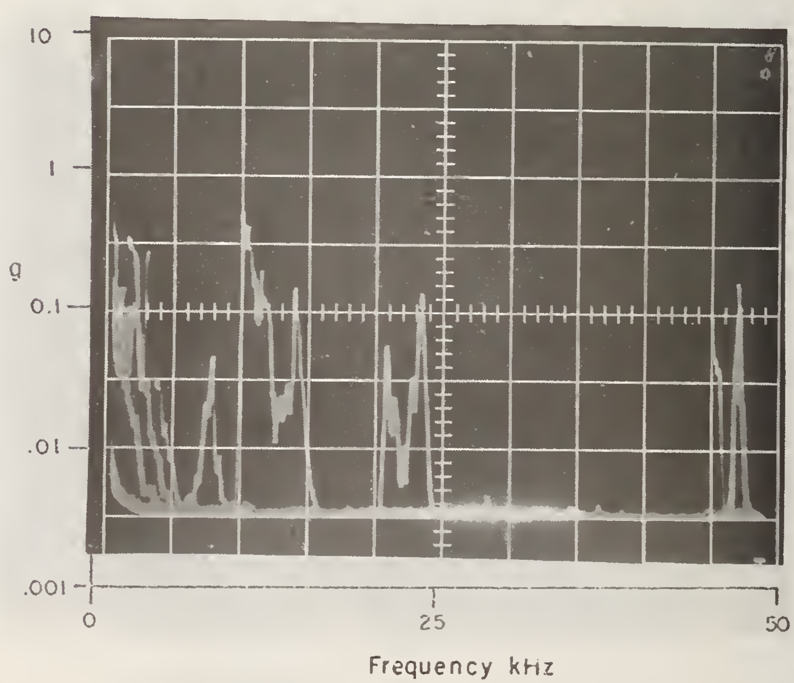


Figure 129. Multiple Sweep Traces of Vibrational Disturbances Resulting from Spalling; Test 14B

Figure 130. Cutting Reinforcing Rod with Bolt Cutters ; Test 14B

5.14 Panel 14

The construction of Panel 14 is shown in figure 125 and is identical to Panel 13 except that two layers of No. 2 reinforcing bars on 6" centers both ways were used instead of the single layer of No. 5 bars.

5.14.1 Test 14B

The attack techniques used in this test were identical to those used in test 13B with the exception that the smaller reinforcing bars could be cut with bolt cutters instead of requiring a burning bar or oxyacetylene torch.

The hole pattern described in test 13B was completed in 2.80 minutes for an average drilling rate of 3.11 seconds per linear inch. Acoustical and vibrational disturbance samples are shown in figures 126 and 127, respectively.

Spalling the bottoms of the 14 drilled holes was accomplished in the planned sequence (5" deep holes first) and required 122 blows from the sledgehammer and 3.56 minutes working time. This represents an average of 8.7 blows and 15.25 seconds per hole. Multiple sweep traces of the acoustical and vibrational disturbances are shown in figures 128 and 129, respectively.

Breakout of the center of the target area required 40 sledgehammer blows and 0.98 minute working time. Spalling from the ten peripheral holes into the broken-out central area with the tapered punch took 1.67 minutes and 64 sledgehammer blows for an average of 10.02 seconds and 6.4 blows per hole.

Finally, as shown in figure 130, the reinforcing rod was cut with 3/8" bolt cutters in 0.74 minute. The 16 cuts required an average time of 2.74 seconds each. The total working time on this test was 9.75 minutes and the elapsed time was 12.24 minutes.

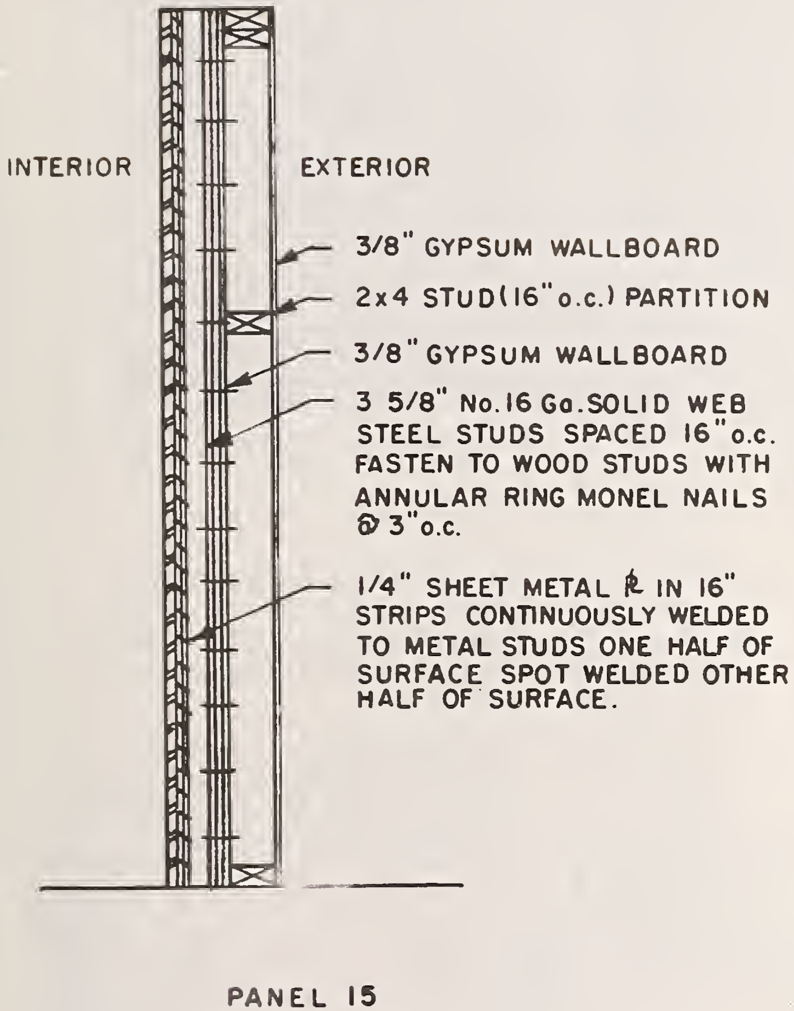


Figure 131. Construction of Panel 15

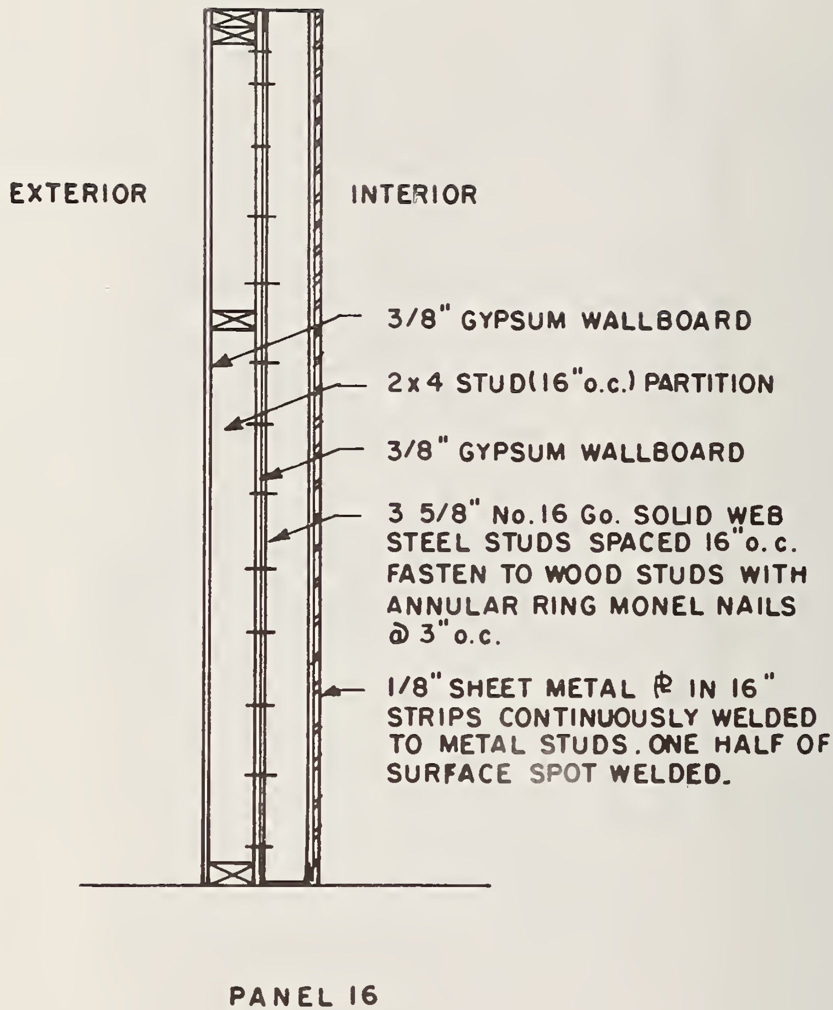


Figure 132. Construction of Panel 16

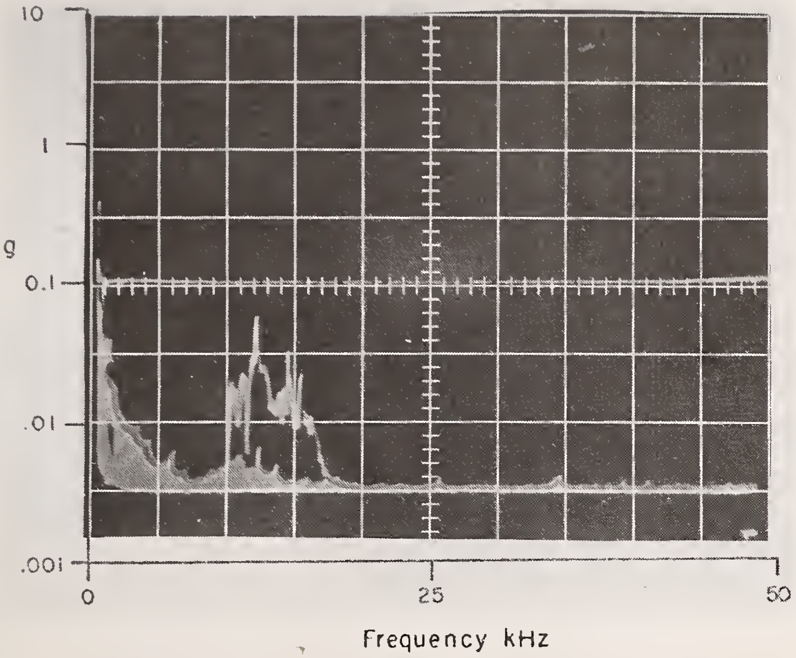


Figure 133. Vibrational Disturbances Resulting from Knocking Out Portions of Wall with Boot Kicks ; Test 15A

Figure 134. Test 15A. Cutting Steel Plate

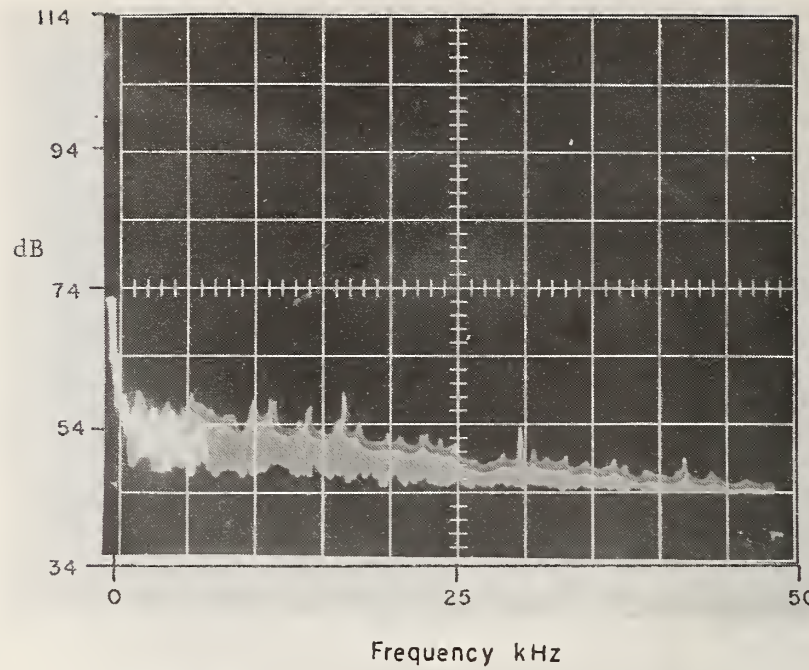


Figure 135. Acoustical Disturbances Produced by Torch Cutting; Test 15A

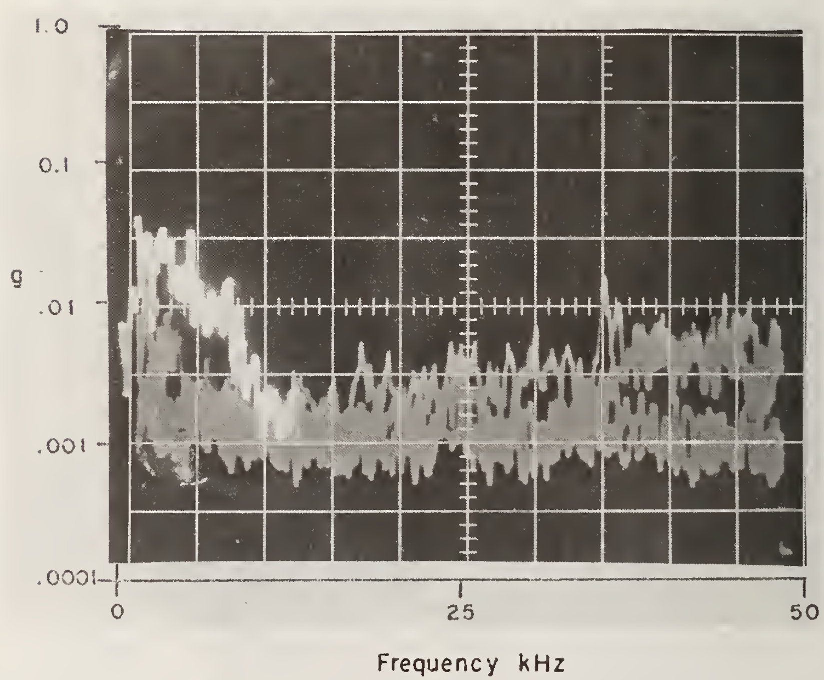


Figure 136. Vibrational Disturbances Produced by Torch Cutting ; Test 15A

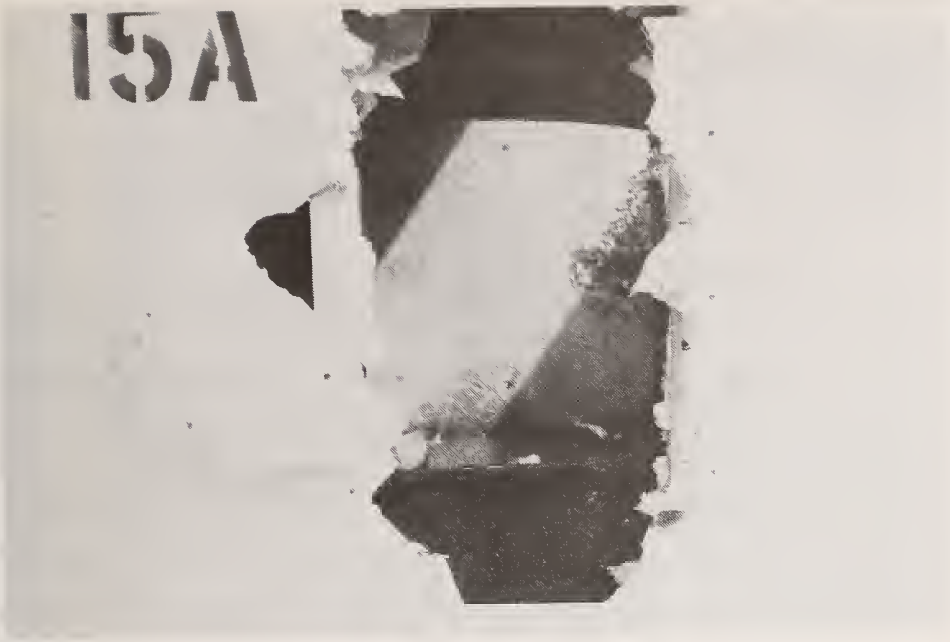


Figure 137. Test 15A. Completed Opening

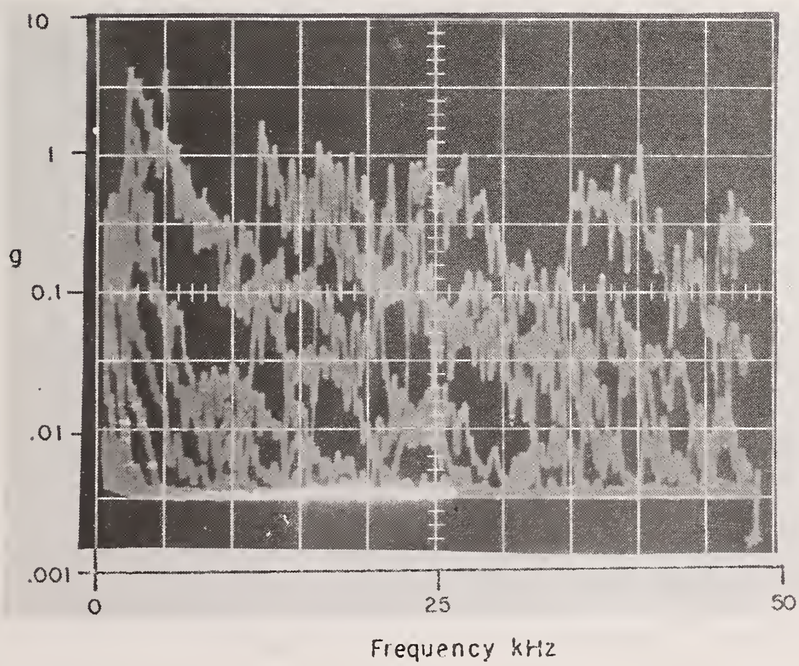


Figure 138. Multiple Sweep Recording of Vibrational Disturbances Produced by Sledge; Test 15A

5.15 Panels 15 and 16

The construction of panels 15 and 16 is shown in figures 131 and 132. Both were 2" X 4" studded walls covered by plasterboard and reinforced with an interior lining of mild steel which was 1/4" thick on Panel 15 and 1/8" thick on Panel 16. The steel reinforcing was cut into 16" wide strips and welded to steel studs which were fastened to the interior side of the wooden studs. Over half the interior of each panel, the steel reinforcing strips were continuously seam-welded to the steel studs. On the other half of each panel, the welding was intermittent 1" long spots on 12" centers.

5.15.1 Test 15A

This test was made in the spot-welded portion of the panel. With several boot kicks, the plasterboard was knocked out on both sides of the wooden studded portions of the wall and the larger broken pieces were cleared out of the way by hand. The working time was 0.64 minute and a sample of the vibrational disturbance is shown in figure 133. Then, as shown in figure 134, the oxyacetylene torch was used to make two horizontal cuts through the steel reinforcing for the full width of the 16" strip. The cuts were separated vertically by a distance of about 16" and were intended to permit this section of the reinforcing to be broken out by sledgehammer by tearing out the spot-welds. The 32 linear inches of torch cutting required 6.86 minutes working time and produced acoustical and vibrational disturbances as shown in figures 135 and 136, respectively. SPL readings of 71 dBC were observed at 12'. The average cutting rate was 12.86 seconds per inch.

When the cuts were complete, 25 blows from the 10-pound sledge fractured the spot-welds and produced the clear opening shown in figure 137. These required 0.76 minute working time and produced the vibrational disturbances shown in the multiple sweep recording of figure 138. SPL readings of 108 dBC were observed at 12' distance during the sledgehammer attack. The total working time was 8.26 minutes and the elapsed time was 8.37 minutes. A savings in elapsed time was realized by lighting off the torch while the plasterboard was being kicked out.

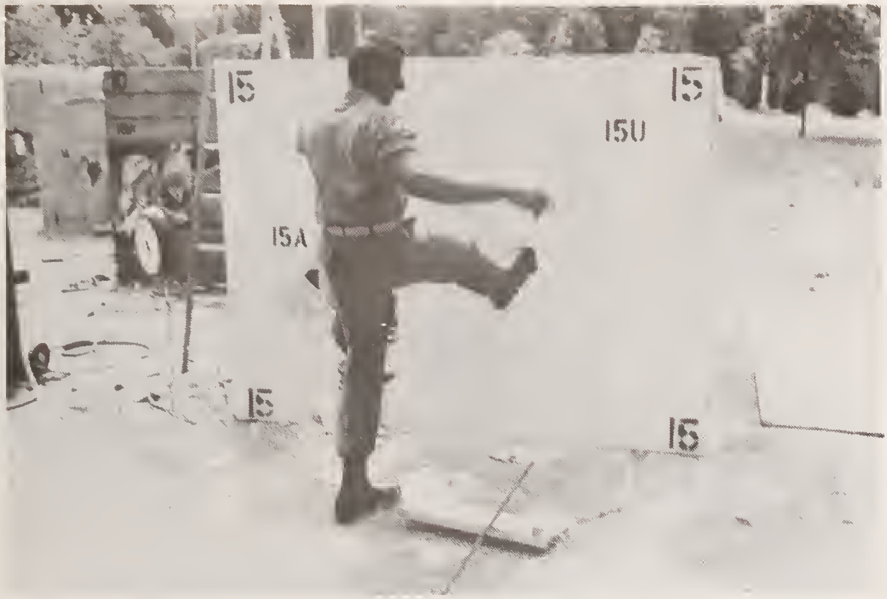


Figure 139. Test 15U. Kicking Out Plasterboard

Figure 140. Test 15U. Opening Produced by Kicking Out Plasterboard

Figure 141. Test 15U. Preparing to Ignite Burner

Figure 142. Test 15U. Cutting with Burning Bar

Figure 143. Test 15U. Final Size of Opening

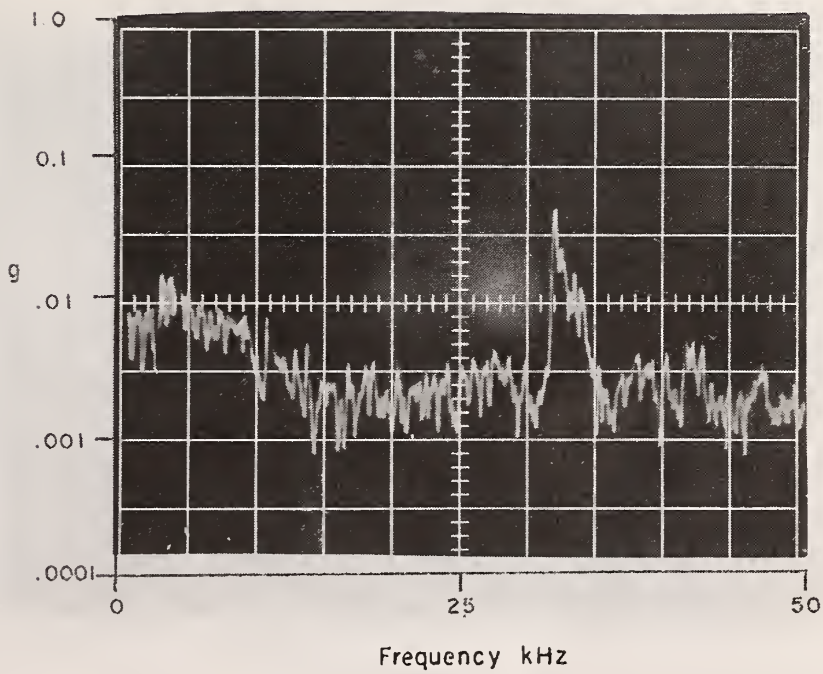


Figure 144. Test 15U. Vibrational Disturbances Produced During Burning

5.15.2 Test 15U

This test was conducted at a location where the steel reinforcing was continuously welded so the entire perimeter of the opening was cut out using the burning bar.

As shown in figures 139 and 140, the plasterboard was kicked and cleared out of the target area in 0.24 minute. Then, figure 141, the burning bar was ignited with the oxyacetylene torch and the steel lining was cut out, figure 142, leaving an opening with dimensions of approximately 12"X 14" as shown in figure 143.

The burning bar was operated at 75 p.s.i. oxygen pressure and consumed 59" of bar in the 1.99 minutes it took to make the opening. The average cutting rate was 2.3 seconds per linear inch. A sample of the vibrational disturbances produced during the burn is shown in figure 144. Acoustical disturbances observed with the microphone at a distance of 20' are shown in figure 145. SPL readings of 82 dBC were observed at a distance of 12'. The total working time was 2.23 minutes and the elapsed time was 3.52 minutes.

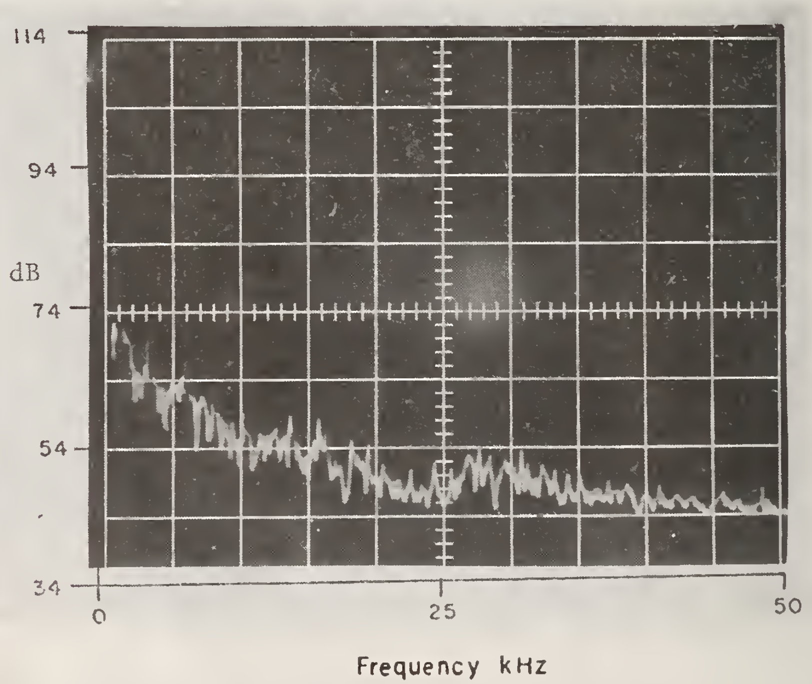


Figure 145. Test 15U. Acoustical Disturbances Observed with Microphone from 20'

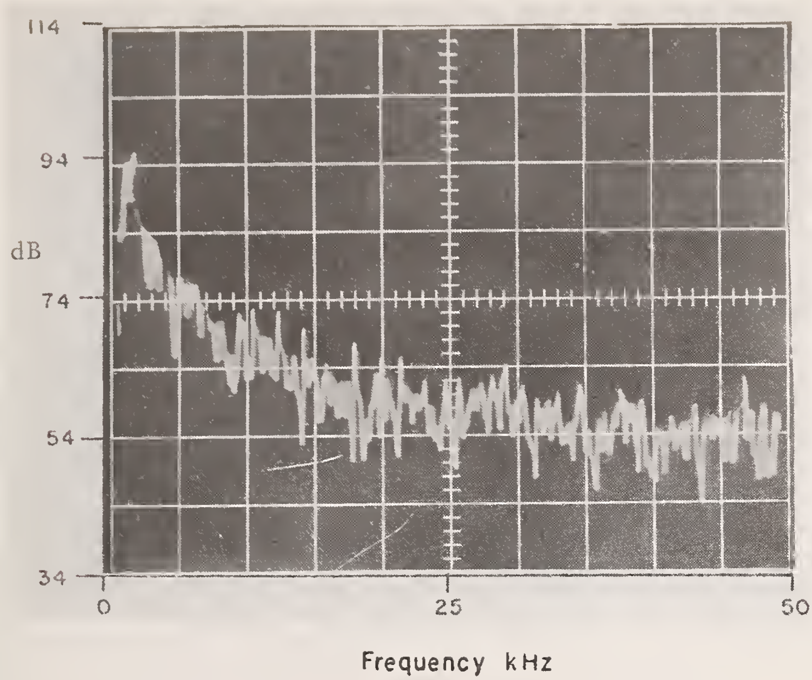


Figure 146. Test 16A. Acoustical Disturbances Produced by Torch

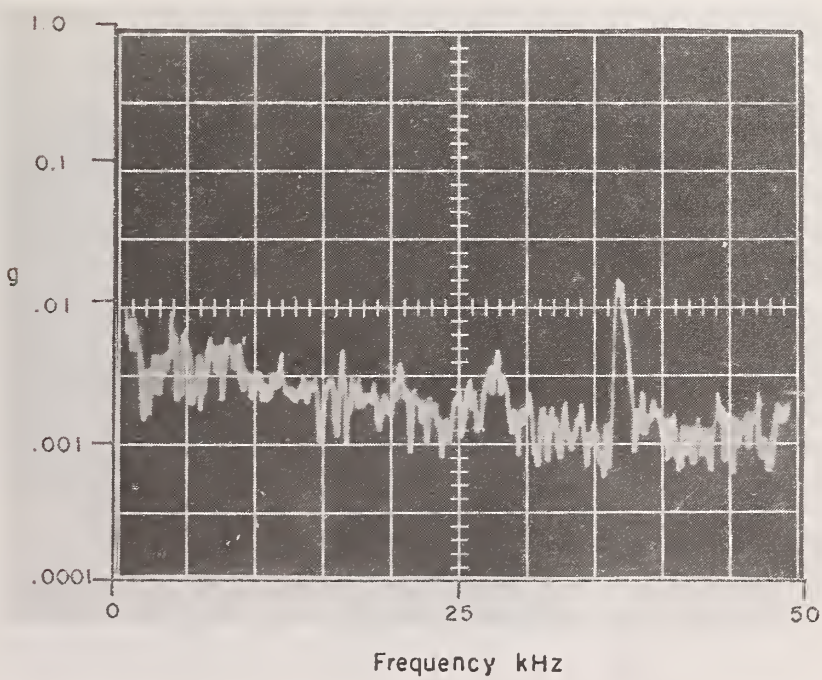


Figure 147. Test 16A. Vibrational Disturbances Produced by Torch

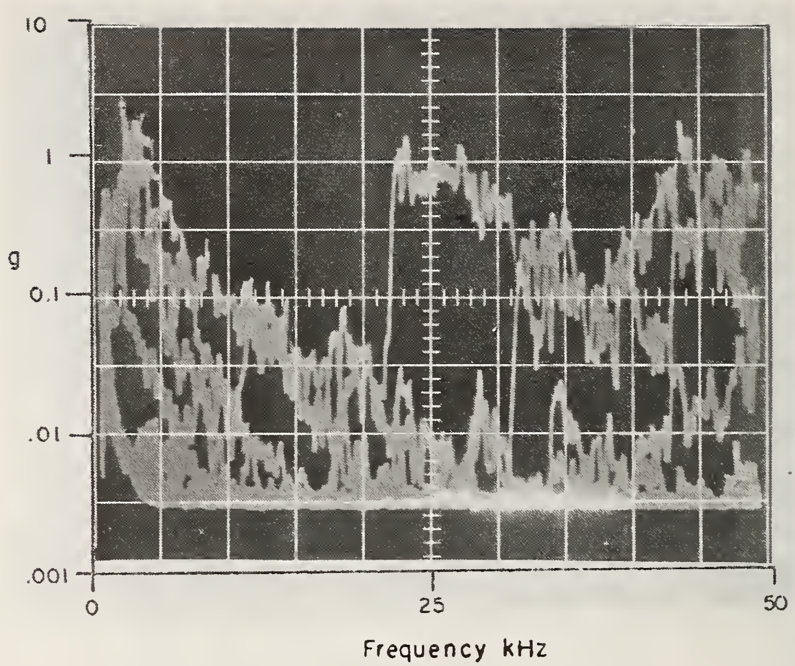


Figure 148. Test 16A. Vibrational Disturbances Produced by Sledgehammer

Figure 149. Test 16A. Final Opening

5.15.3 Test 16A

Test 16A was conducted on the spot-welded portion of Panel 16.

The sledgehammer was used to break out the plasterboard with four blows and 0.38 minute working time. Then the two horizontal cuts were made with the oxyacetylene torch. The time required for this was quite long; 5.51 minutes which represents an average cutting rate of 10.33 seconds per inch. Samples of the acoustical and vibrational disturbances produced by the torch are shown in figures 146 and 147, respectively.

The spot-welds were broken out with seven blows from the 10-pound sledgehammer in 0.26 minute working time. A multiple sweep recording of the vibrational disturbances produced by the sledgehammering is shown in figure 148.

The final opening is shown in figure 149. It took 6.15 minutes working time and 7.63 minutes elapsed time to complete.

The torch operator felt that there had been improper flow settings on the cutting torch, so, after readjusting torch controls, but not gas pressures, two similar cuts were made in an adjacent section of the reinforcing. These were completed in 2.14 minutes working time with an average cutting rate of 4.48 seconds per inch, more than twice as fast as the first cuts. Three blows from the sledgehammer completed the opening in 2.39 minutes working time. Allowing 0.38 minute (the value measured on the first attempt) to clear out the plasterboard, the second penetration was completed in an estimated working time of 2.77 minutes.

5.15.4 Test 16U

This test was conducted on the continuously-welded portion of Panel 16.

The plasterboard was kicked out of the target area in 0.46 minute. Then a two section (20') long burning bar was used (see fig.150) to cut through the steel reinforcing. It was operated at 75 p.s.i. oxygen pressure and consumed 52" of bar in the 1.45 minutes working time required to make the approximately 9" X 12" opening shown in figure 151. Acoustical and vibrational disturbances are shown in figures 152 and 153, respectively. SPL readings at 12' were 86 dBC. Total working time was 1.91 minutes and elapsed time 2.70 minutes.

Figure 150. Burning Bar Cutting Through Steel Reinforcing; Test 16U

Figure 151. Hole Produced by Burning Bar; Test 16U

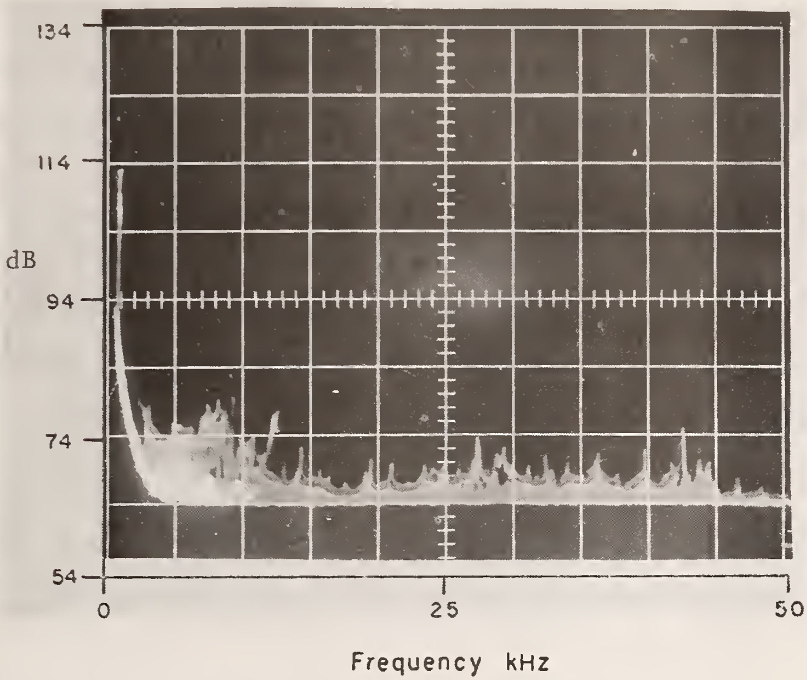


Figure 152. Acoustical Disturbances Produced by Burning Bar; Test 16U

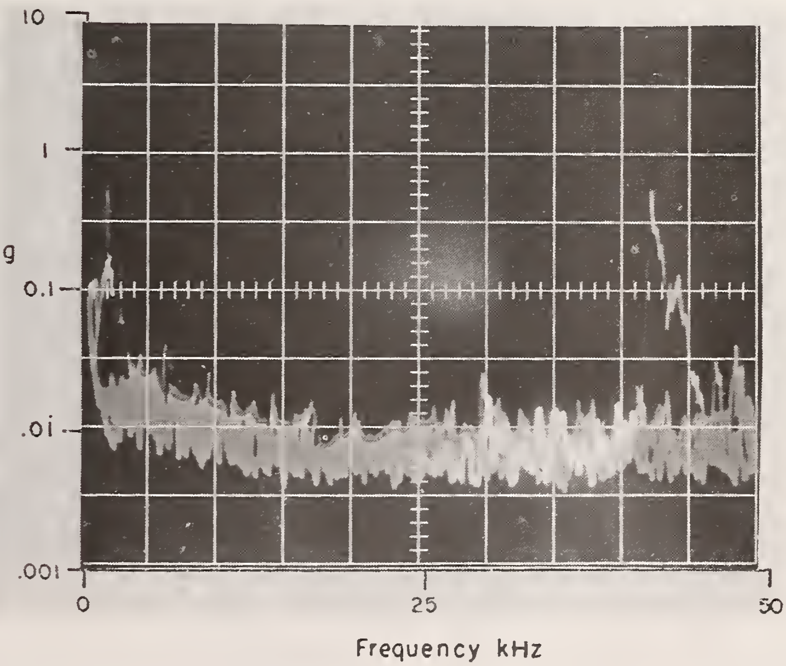


Figure 153. Vibrational Disturbances Produced by Burning Bar; Test 16U

Because the length of the bar in this test was such as to make it unwieldy and difficult to handle, a second penetration was made with a shorter bar. This time a 10" X 13-1/2" opening was made in 1.06 minutes, consuming only 39" of bar. This represented an average cutting rate of 1.35 seconds per linear inch. Allowing the same time for clearing the plasterboard as in the first penetration (0.46 minute) this test could have been completed in an estimated total working time of 1.52 minutes. A single sample of the vibrational disturbances during the second burn is shown in figure 154.

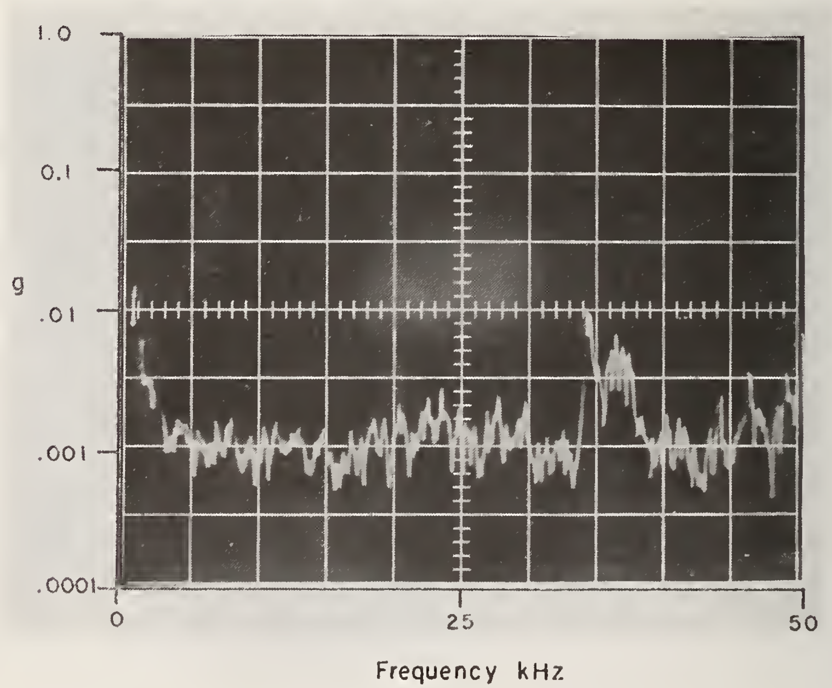


Figure 154. Single Sample of Vibrational Disturbances Produced by Second Burning; Test 16U

6. DISCUSSION OF BARRIER PANEL TEST RESULTS

The time required to penetrate a given structural barrier is dependent upon a number of factors in addition to the materials and techniques used in the construction of the barrier itself. The power and sophistication of the tooling used to make a penetration is important but often the selection of the best tooling may have less influence on the penetration time than will skill and expertise in exploiting the capabilities of that tooling through utilization of optimum attack techniques. Test 16A illustrates this point. In a second attempt on this test,the working time was more than halved using the same tooling as in the first penetration.

The skill, strength and numbers of the intruders are significant factors in most penetrations. The ubiquitous sledgehammer was a necessary tool in most of the tests, but it's effectiveness is dependent upon the power and accuracy with which it's blows can be delivered. Even a powerful man appears to find it difficult to sustain a vigorous sledgehammer attack for more than a minute or two without rest, and a five- or six-man team would probably be required to maintain a continuous sledgehammer attack for as much as 30 minutes.

Foreknowledge of barrier construction is a significant factor as without this it is possible to damage or destroy tooling which may encounter unexpected materials. This will always delay, and, at times, may even frustrate an attempted penetration.

Available working space will certainly influence the time required to make a penetration. This test series did not attempt to investigate this factor but its influence has been observed occasionally on prior tests.

Inadequate ventilation at a target area can increase the time required for a penetration as several of the more useful tools produced copious amounts of dust, fumes, heat or smoke which may quickly render an enclosed and poorly ventilated area uninhabitable. Gasoline-powered tools, and especially the abrasive wheel cutoff saw, are particularly liable with respect to fumes and dust, and the burning bar with respect to sparks, heat and smoke.

The accessibility of the target area to vehicular traffic is another important but unmeasured consideration. Some of the attack tooling or support facilities, such as oxygen tanks or portable electric power generation equipment, are not easily transported for long distances without vehicular assistance.

The experience reflected in the planning and execution of a penetration can have a large influence in the efficiency of the effort and the minimization of the time that is required.

Motivitation is probably a more significant factor in a test series such as this than it is in a penetration made to further some nefarious objective. In the latter instance, the motivation must be great enough to offset the risk of detection and apprehension. In a test series, this real sense of pressure is missing and some sort of substitute, such as a sense of competition, must be utilized.

It is believed that the best of most of these factors were present in this test series. The power and sophistication of the tooling available reflected the state-of-the-art of reasonably portable tooling, excepting only explosives which were ruled out by choice. One or more operators were experienced in the use of virtually all items of tooling. The attack team had members of outstanding strength and stamina and, in all but a couple of tests, were sufficiently numerous so that individual operator fatigue was not a major factor. There was foreknowledge of the construction of each barrier panel, ample working space and the unrestricted ventilation afforded by an outdoor test site freely accessible to vehicular transportation. Test participants included members of the security community with many years of collective experience in planning and conducting barrier penetrations. This experience has resulted in the evolution of techniques which have reduced the time necessary to penetrate eight-inch thick concrete by a significant factor in the course of four test series which have been conducted during the past two years. For these reasons it is believed unlikely that the shortest working times recorded for any one of these tests would be significantly bettered by an actual intruder attacking a like barrier with comparable tools.

Table 2 is a summary listing of the test results showing the tooling, in abbreviated form, and the measured or calculated time to make each penetration.

Table 2. Summary of Test Results

Test	Tooling Employed	W (Working time, min.)
1A	Sledge, torch	3.84
1A	Calculated based on repeat of torch cut	3.06
1K	Rotohammer, punch, ram, sledge, torch	10.22
2A	Sledge, cutting maul	25.56
2B	Rotohammer, punch, sledge, bar	26.55
3MA	Abrasive wheel, pry bar, sledge	9.17
3A	Cutting maul, ram, sledge	3.84
4A	Abrasive wheel, sledge, bar	7.87
4AM	Abrasive wheel (shallow cut), bar	2.64
4B	Cutting maul, sledge	1.90
5A	Sledge	4.42
5K	Ram, sledge	7.53
6B	Rotohammer, punch, sledge, torch, bar	10.87
6K	Bar, bolt cutters	4.91
7A	Sledge, cutting maul, bar, bolt cutters	10.70
7A	Calculated, using abrasive wheel instead of cutters	6.30
7A	Calculated, using torch instead of cutters	9.82
8A	Sledge, bar, bolt cutters	10.33
8A3	Sledge, abrasive wheel	9.83
9N	Electric saw, sledge, pry bar, drill, abrasive wheel	9.94
9M	Hubless saw, sledge, abrasive wheel	7.46
9M	Calculated, based on repeat of abrasive wheel cut	6.01
10N	Ram, sledge, cutting maul	6.73
11U	Cutting maul, sledge, bolt cutters	6.83
12U	Cutting maul, sledge, drill, saber saw, sledge	12.13
12	Gasoline saw, hubless saw, sledge	6.79
13B	Rotohammer, punch, sledge, taper punch, burning bar	9.52
14B	Rotohammer, punch, sledge, taper punch, bolt cutters	9.75
15A	Kick, torch, sledge	8.26
15U	Kick, burning bar	2.23
16A	Sledge, torch, sledge	6.15
16A	Calculated, based on repeat of torch cut	2.77
16U	Kick, burning bar	1.91
16U	Calculated, based on repeat with shorter bar	1.52

Average working time required to make a penetration for this group of barrier panels 7.85 min.

In table 3 the 16 barrier test panels have been ranked in order of decreasing time required to make the fastest penetration observed during the test series, W. In addition, estimates are given for X, the penetration resistance of unreinforced barriers; W-X, the added resistance imparted by the reinforcing (zero for initial construction panels 1, 13 and 14); C, normalized cost (total cost for panels 1, 13 and 14, cost of reinforcing for all others) and R, relative cost-effectiveness.

Table 3

Panel	W	X	W - X	Cr or C*	Rr or R*
2	25.56	.75	24.81	3.72	6.67
8	9.83	.75	9.08	3.87	2.35
14	9.75	0	9.75	5.27*	1.85*
13	9.52	0	9.52	5.15*	1.84*
11	6.83	1.5	5.53	3.11	1.71
12	6.79	1.5	5.29	3.09	1.71
10	6.73	1.5	5.23	1.00	5.23
7	6.30	.75	5.55	3.96	1.40
9	6.01	1.5	4.86	1.71	2.84
6	4.91	.75	4.16	1.65	2.52
5	4.42	1.63	2.79	1.65	1.69
3	3.84	.75	3.09	5.64	0.55
1	3.06	0	3.06	1.85*	1.65*
15	2.23	.25	1.98	4.30	0.46
4	1.90	.75	1.15	6.17	0.19
16	1.52	.25	1.27	3.94	0.32

6.1 Conclusions

Table 3 displays a number of unexpected results. Foremost of these is the surprisingly high penetration resistance of Panel 2. In earlier tests mortar-filled cinder block with brick veneer had been penetrated in 2.1 minutes[1/] and four-inch thick fibrous concrete with steel reinforcing had only held up against a sledgehammer attack for 9.43 minutes[2/]. While Panel 2 was concrete rather than cinder block and the cores were well filled with a void-free mortar, it lacked the brick veneer and its fibrous concrete liner was only three inches thick and did not contain reinforcing bars. Nevertheless it demonstrated a penetration resistance time against two different attack techniques which was more than double the sum of the times previously observed on presumably comparable individual components. It was also more than double the penetration time required for either of the eight-inch thick, reinforced, lightweight concrete panels (Panels 13 and 14).

Of the alternative methods for reinforcing hollow eight-inch concrete blocks which were tested, the ferro-cement liner used on Panel 8 was best by a considerable margin.

In the case of the 2" X 4" studded barriers, none of the experimental reinforcing techniques developed as much as seven minutes penetration resistance, however, Panels 10, 11 and 12 were all above 6.5 minutes. Of these, Panel 10 exhibits the higher cost-effectiveness and would appear to be the preferred choice.

1/ NBSIR 73-223, Penetration Tests on JSIIDS Barriers, June 4, 1973, R. T. Moore.

2/ NBSIR 73-101, Penetration Resistance Tests of Reinforced Concrete Barriers, December 1972, R. T. Moore.

Most of the remaining experimental panels exhibit values of penetration resistance, frequently coupled with low-cost-effectiveness, that would appear to argue against their application in situations where security requirements were more than minimal.

The performance of several of the reinforcing materials and the observed limitations in tooling capabilities suggest several intriguing new barrier design concepts:

(1) Add to the interior of Panel 2 a 3/16"-thick steel plate which is bonded to the fibrous concrete by means of 1-1/2" annular ring nails on 6" centers both ways. The nails are inserted in pre-drilled holes in the steel plate prior to casting the fibrous concrete. Such a liner would be expected to further impede the spalling of the fibrous concrete and force the ultimate use of flame cutting.

(2) Increase the thickness of the ferro-cement liner used in Panel 8. The Panel 8 liner was only about 2" thick and was quite effective for such a small thickness section. Thickness might be increased by additional layers of chain link fencing tied in place prior to mortoring or alternatively by making up two liners similar to that in Panel 8 with a 1-1/2" thick sandwich of plywood between them.

(3) Add a fibrous concrete liner to the interior of Panel 12. This would be expected to defeat the straightforward "two-cut and sledgehammer" attack used in test 12 and would be likely to ruin the hubless saw blade in the process. Such a barrier would be considerably lighter in weight than Panel 2 but might have comparable penetration resistance.

The barrier test results reported here and prior test series (1, 2) results indicate a potential need for a research and development effort, supported by appropriate test and evaluation, with the objective of producing designs for cost-effective physical security barriers capable of resisting penetration for specified working time intervals. In a given security application, the necessary penetration resistance time must be based on the maximum amount of time between the initial detection of a

penetration attempt and the response generated by that alarm. All of the penetration tests produced acoustic, ultrasonic or vibrational, or both, disturbances which should be readily detectable by appropriate intrusion alarm equipments. Assuming that such equipments are employed, it would be desirable to select a physical barrier having penetration resistance commensurate with alarm response time.

7. FENCE TESTS

The fence tests were conducted on an enclosure 100' long and 20' wide equipped with two double-hung gates. One-half of the enclosure and one set of gates was constructed from American made materials. The remainder was constructed from metric gauge materials which were obtained from a major European manufacturer of fencing. Two U.S.gauge and five metric gauge fencing fabrics were used.

The U. S. gauge fabric was 7' high and in accordance with Federal Specification RR-F-00191/1. Corner posts were 2.875" outside diameter zinc-coated steel, weighing at least 5.79 pounds per lineal foot, and intermediate posts were 2.375" outside diameter, weighing 3.65 pounds per lineal foot. Corners were braced with 1.625" diameter horizontal braces and 0.375" diagonal truss rods with turnbuckles. A tension wire was erected near the top of the fence and a 0.375" diameter tension messenger cable was erected 4" from the bottom of the fence. The fabric was attached to these tension members by wire ties at intervals of about 16". Outward sloping outriggers were mounted on the posts and vertical outriggers were mounted on the gate and these carried three strands of barbed wire.

The metric gauge fence fabric was 2 meters high. Poles were steel tubing coated with green vinyl. Corner poles were 60 mm outside diameter and were braced by two diagonal 40 mm outside diameter poles. Intermediate poles were 50 mm outside diameter 1.8 mm wall thickness. Five tension wires were strung at 40 cm intervals from top to bottom of the fencing and were attached to the poles by plastic fasteners which plugged into pre-drilled holes in the poles. The fabric was tied to the tension wires with wire wraps at intervals of about 40 cm. No out-riggers or barbed wires were mounted on the metric gauge portion of the

Figure 155. Fencing Using American Fittings
To Attach Tensions Bars to Poles

Figure 156. Overview of Site Configuration
of Fences during Tests

enclosure, but a short three-coil pyramid of concertina wire was set up on the inside of one of the metric fence sections and held in place with wire ties to garden type steel fence posts. The metric portion of the fence was constructed by following to the greatest extent possible the rather limited instructions which were supplied by the manufacturer. Where these were found lacking, improvisation was necessary. In particular, American-made fittings were used to attach the tension bars to the poles, as shown in figure 155.

All poles in both halves of the enclosure were set in concrete-filled holes 3' deep. An overview of the site configuration during the tests is shown in figure 156.

7.1 Test Instrumentation

The test instrumentation arrangements were the same as used on the barrier panel tests with certain exceptions. Most of the fence tests produced relatively low levels of acoustical disturbances. These generally were below the ambient noise level produced by some heavy construction equipment that was operating nearby so little meaningful acoustical data could be collected. The vibrational disturbance data were obtained from transducers which were mounted on a wire of the fence fabric at various (reported) distances from the attack location. After the first few tests, it was obvious that very little high frequency vibrational components were being produced so the bandwidth of the spectrum analyzer was reduced to 100 Hz and the sweep rate reduced to 300 Hz per centimeter to provide increased resolution in the resulting 3 kHz bandwidth.

7.2 Attack Techniques

A generally similar series of attacks was used on all seven of the sections of fencing. These included climbing the fence using one or more variations in technique or equipment; lifting the bottom of the fence up using a 10' length of 2" X 4" timber as a lever and holding it up while a man crawled under; and cutting the mesh with a variety of tools. In the latter attack, a series of mesh wires would be cut along a diagonal beginning at the bottom of the fence and continuing until a vertical height of 14" above the bottom tension wire (or messenger)

Figure 157. Fence Lifted 12" Using 2" X 4" Timber as Lever; Test F1

Figure 158. Climb Over Fence Using Tarpaulin as Protection against Barbed Wire; Test F1

Figure 159. Climb Over Fence Using Wire Ladder; Test F1

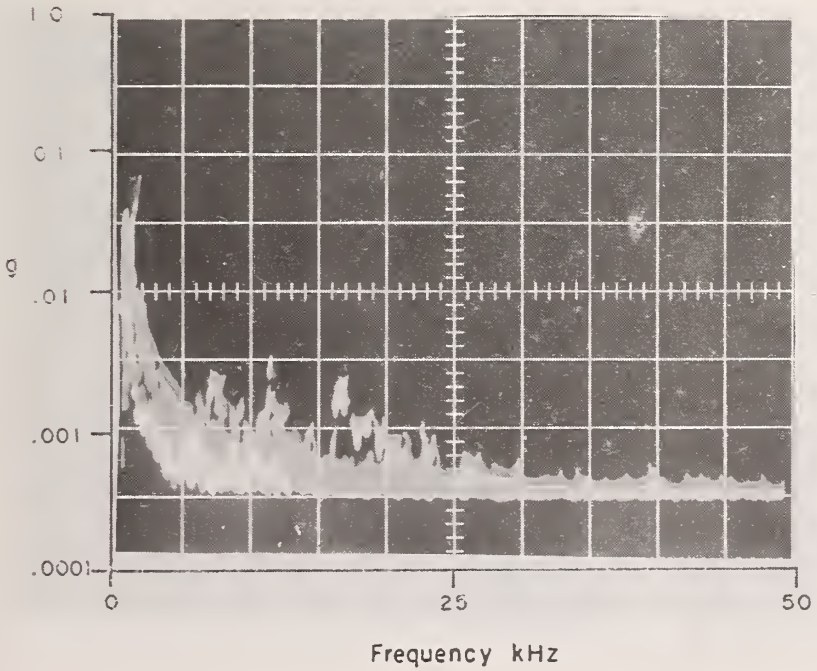


Figure 160. Vibrational Disturbances Observed 15' Away During Placing of Wire Ladder and Climb Over; Test F1

Figure 161. Climb Over Fence Using Linesman's Pliers to Make Steps ; Test F1

Figure 162. Opening Produced by Cutting 13 Wires with No. 14 Bolt Cutters; Test F1

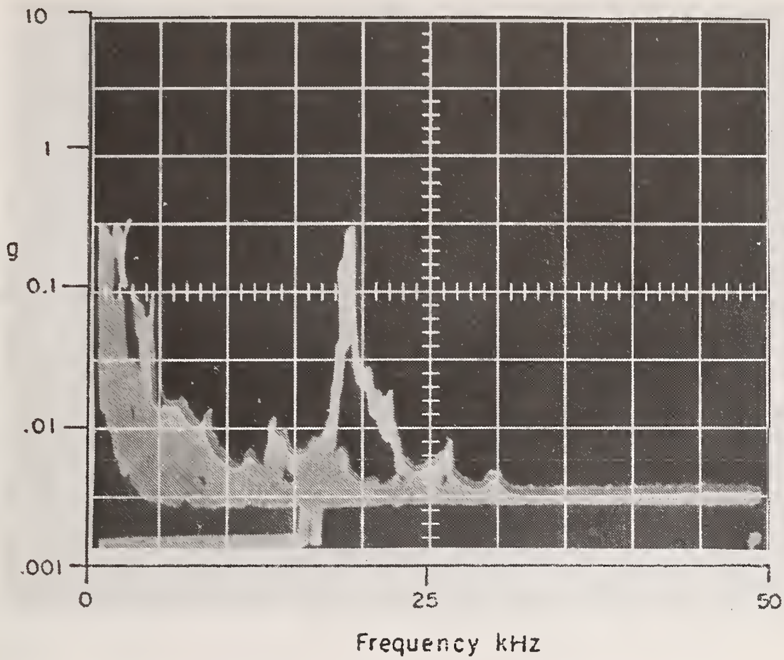


Figure 163. Vibrational Disturbances Observed with Transducer 10' from Attack Point; Test F1

Figure 164. Cuts Being Made with Combination Fencing Tool; Test F1

had been reached. This would produce a flap which would freely hinge back to provide a clear 96 square inch (or larger)opening. Successive cuts using alternative tools would be made cutting the same number of wires one mesh interval away from the original cut. In a few instances other attacks which will be described were made.

7.2.1 F1. Fence section F1 was No. 9 gauge, 2" mesh, galvanized wire.

Despite the 3/8" messenger cable at the bottom of the fence, it could be lifted 12" using the 2" X 4" timber as a lever as shown in figure 157. It took 0.10 minute to lift and one man to crawl under.

A climb over the top was made in 0.15 minute using a folded tarpaulin for protection against the barbed wire as shown in figure 158. That time included throwing the tarpaulin in place.

As shown in figure 159, another climb over the top was made using a wire ladder. The ladder was thrown over the top of the fence and the inside end was attached to the fence fabric using a pair of carabiners. The time required to place the wire ladder and climb over was 0.46 minute. Vibrational disturbances as observed with a transducer approximately 15' away are shown in figure 160.

Another climb was made as shown in figure 161 using linesman's pliers to make steps. One handle of the pliers is inserted through the mesh of the fabric and the downward pointing jaws of the pliers are inserted in the next lower mesh opening. This wedges the pliers in place with the remaining handle hanging outward for use as a handhold or step. This tends to be somewhat slow and awkward and 1.13 minutes were used on this climb.

Using the No. 14 bolt cutters, it took 0.32 minute to cut 13 wires and produce the opening shown in figure 162. With the transducer 10' from the attack point, the vibrational disturbances were as shown in figure 163.

Cuts were attempted with a pair of vise grip cutters and with 8" linesman's pliers, but neither were heavy enough to cope with the No. 9 gauge wire. The cutting slots of a combination fencing tool were adequate however, and, as shown in figure 164, the 13 cuts were made in 0.76 minute producing the vibrational disturbances shown in figure 165.

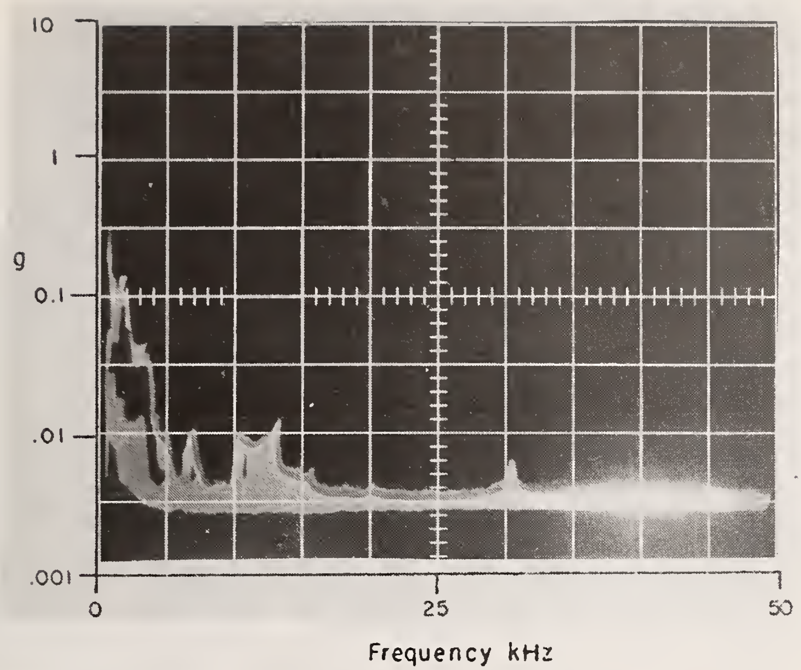


Figure 165. Vibrational Disturbances Produced During 13 Cuts with Combination Fencing Tool ; Test F1

Figure 166. Abrasive Wheel Saw in Use; Test F1

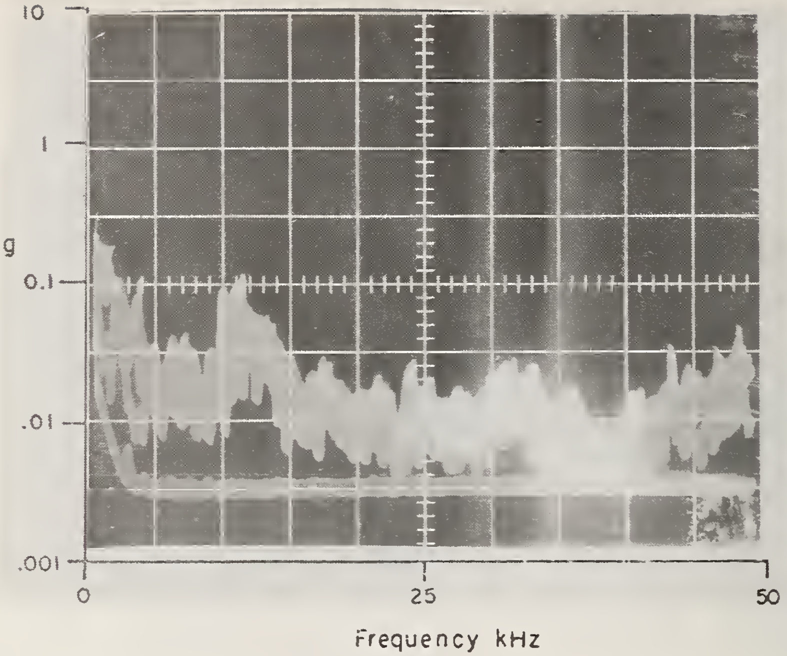


Figure 167. Vibrational Disturbances Produced by Abrasive Wheel Saw; Test F1

Figure 168. Cutting Wires which Attach Outriggers to Tops of Poles; Test F1

Figure 169. Outriggers, Still Attached to Barbed Wire, Cut, Pulled Down and Used as Hand and Foothold to Climb Over Fence; Test F1

Figure 170. Abrasive Wheel Saw Used to Cut Nearly Full Height of Fabric and also to Cut Off One Intermediate Post; Test F1

Figure 171. Gloved Hand Climb Over at Gate where Barbed Wire Outriggers Were Vertical; Test F1

Figure 172. Gloved Hand Climb Over Started from Inside of Fence; Test F1

Figure 173. Placing 2 X 4 in Position;
Test F2

Figure 174. First Man Crawling under F2;
Test F2

Figure 175. First Man Inside the Enclosure; Test F2

Figure 176. Beginning to Crawl under F1; Test F2

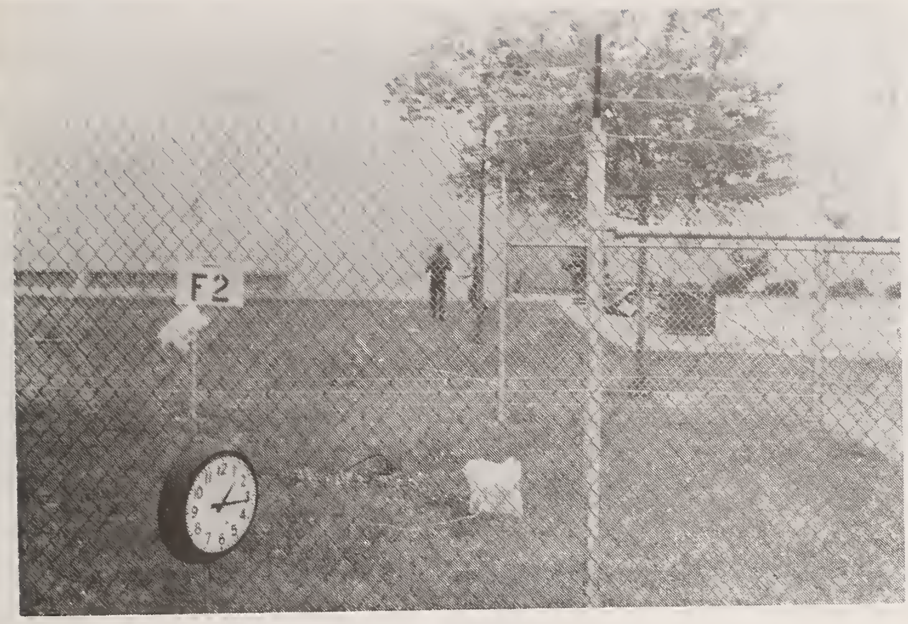


Figure 177. Both Men 50' Behind Second Fence; Test F2

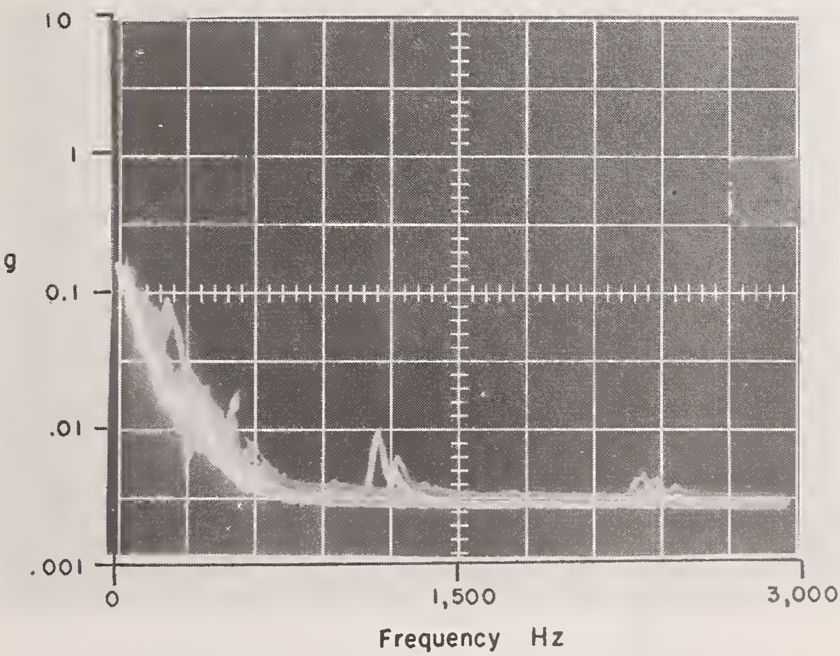


Figure 178. Vibrational Disturbances Produced by Diagonal Cutters at 6'; Test F2

The abrasive wheel saw was then used, as shown in figure 166, to make two cuts and form a triangular opening 17"wide and 15" high. This required 0.17 minute working time and 0.48 minute elapsed time and produced vibrational disturbances, as shown in figure 167. The transducer was approximately 12' from the attack location.

Then, as shown in figure 168, the wire ties attaching the outriggers to the tops of the poles were cut. Two of the outriggers were removed and, with the barbed wire still attached, it was pulled down and used as a hand and foothold to climb over the fence, as shown in figure 169. Leather gloves were used for hand protection during the climb over. This was a rather slow technique and required 1.12 minutes.

Later, the abrasive wheel saw was used to make a cut for nearly the full height of the fabric in 0.26 minute and to cut off one of the intermediate posts in 0.34 minute, as shown in figure 170.

Two more gloved hand climb overs were made. One was at the gate where the barbed wire outriggers were vertical rather than sloping. As shown in figure 171, this required 0.06 minute. The other, as shown in figure 172, was started from the inside of the fence and took 0.08 minute.

7.2.2 F2 Fence section F2 was No. 11 gauge, 2" mesh, vinyl-coated wire and was otherwise identical to F1 and for this reason no climbs were made over the top.

Using the 2" X 4" timber, the bottom of the fence was lifted and a man crawled under in 0.14 minute. Then, a more dramatic test was set up. Two men started from a point 30' away from F2 and, using the 2" X 4" timber to lift the bottom of the fence, one crawled under and then pulled the 2" X 4" inside and lifted the fence for the second man. With both men inside the enclosure, they ran the 20' to F1 and repeated the process. Then they ran to a point 50' beyond F1. The total time for the two men to run 100' and crawl under the two fences was 0.95 minute. The sequence of events is shown in figures 173, 174, 175, 176, and 177.

Figure 179. Opening Produced by Abrasive Wheel Saw; Test F2

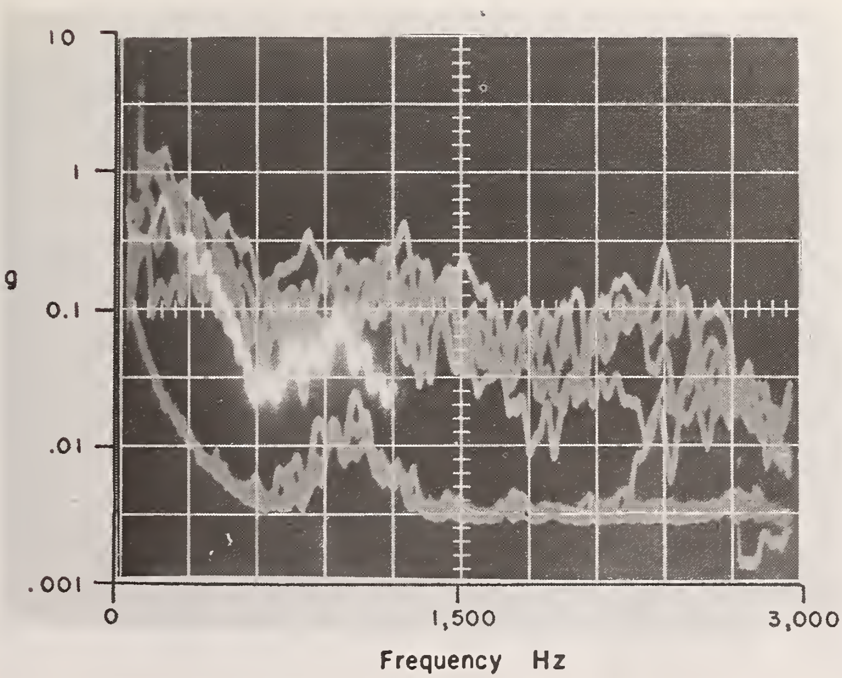


Figure 180. Multiple Sweeps of Vibrational Disturbances Produced by Abrasive Wheel Saw; Test F2

As in the case of F1, it required cutting 13 wires to make the necessary opening size in the fence fabric. With the No. 14 bolt cutters, this took 0.27 minute. It took 0.79 minute with the vise grip cutters, 0.39 minute with the linesman's pliers, and 0.59 minute using a pair of 6" diagonal cutters. Vibrational disturbances from the diagonal cutters at a distance of 6' are shown in figure 178.

The abrasive wheel saw was used to make a 21" long diagonal cut and a 22" horizontal cut and produce the opening shown in figure 179. in 0.44 minute. Multiple sweeps of the vibrational disturbances are shown in figure 180. These data were obtained with the transducer only two to three feet from the attack location.

Figure 181. 25" High Opening Produced in Lighter Gauge Material; Test F3

Figure 182. Appearance of Fabric after Dropping ; Test F3

Figure 183. Climbing Fence Bare-handed; Test F3

Figure 184. Pulling Down Fabric from Top Tension Wire in Preparation for Climb-over, Test F3

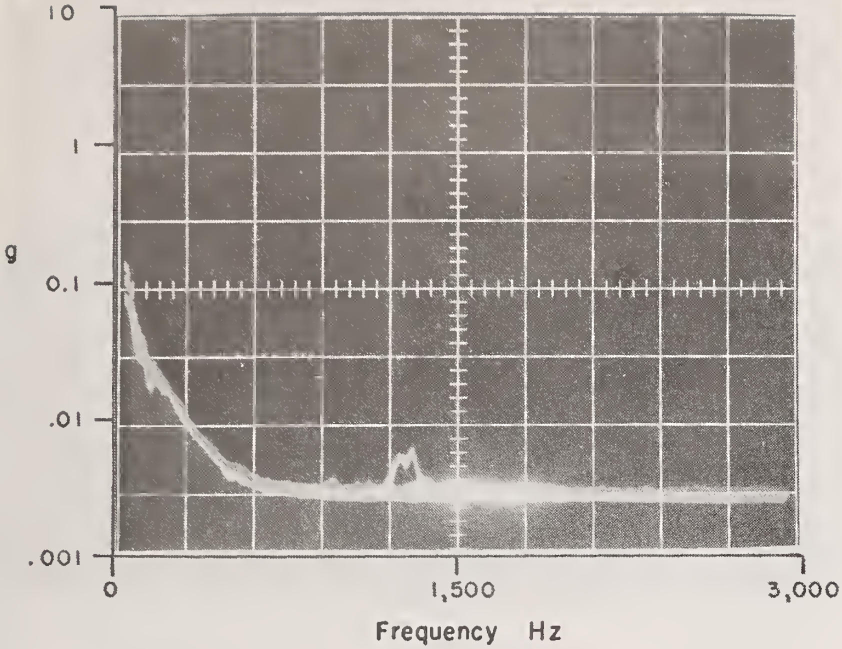


Figure 185. Vibrational Disturbances Produced by Vise Grip Cutters; Test F3

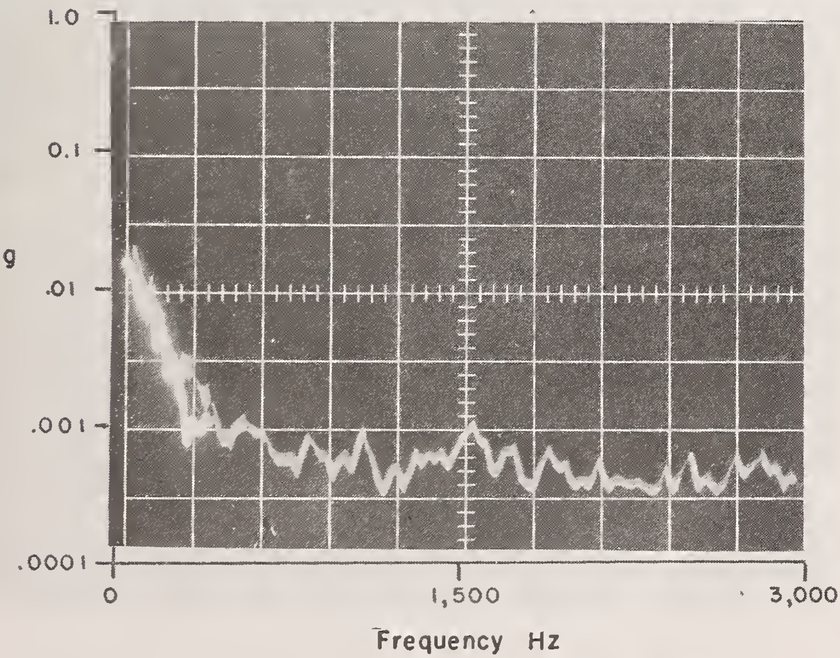


Figure 186. Vibrational Disturbances Produced by 6" Diagonal Cutters; Test F3

Figure 187. Completed Opening;
Test F3

7.2.3 F3 F3 was 40 mm mesh with 1.8 mm wire, vinyl-coated.

Here, because of the lighter gauge material, it was possible to grasp the fabric and tear it clear of the wire ties fastening it to the bottom tension wire and make the 25" high opening shown in figure 181. It took 0.12 minute to make this opening and for one man to crawl through. Note in figure 182 that when the fabric is released afterwards the damage is not highly obvious and could easily be missed by a casual inspection of the fencing.

As shown in figure 183, climbing the fence was accomplished bare-handed in 0.07 minute.

As shown in figure 184, the fabric could be readily pulled down from the top tension wire and this with crawl-over took only 0.10 minute.

Because the bottom tension wire was close to the ground, only 12 wires had to be cut to make the required opening size in this fabric. This required 0.32 minute using the No. 14 bolt cutters and 0.39 minute using the vise grip cutters. The vibrational disturbances from this were barely above the background with the transducer 9' from the attack point; see figure 185.

Using the lineman's pliers, the 12 cuts took 0.33 minute, and using the 6" diagonal cutters, it took 0.21 minute. Vibrational disturbances are shown in figure 186 with increased gain.

As a final test on this fabric, one of the wires was cut near the bottom of the fence. Then the cut end was gripped with pliers and pulled. The wire which is pulled visibly straightens for about half the height of the fence. It was cut again at the highest point where it can be readily identified and then was readily stripped clear out of the fabric. The process was repeated on the top half of the fence and produces a full opening, as shown in figure 187. This procedure took 0.58 minute. It is more easily accomplished with vinyl-coated wire than galvanized as the vinyl coating reduces friction making it possible to remove the wire in longer sections.

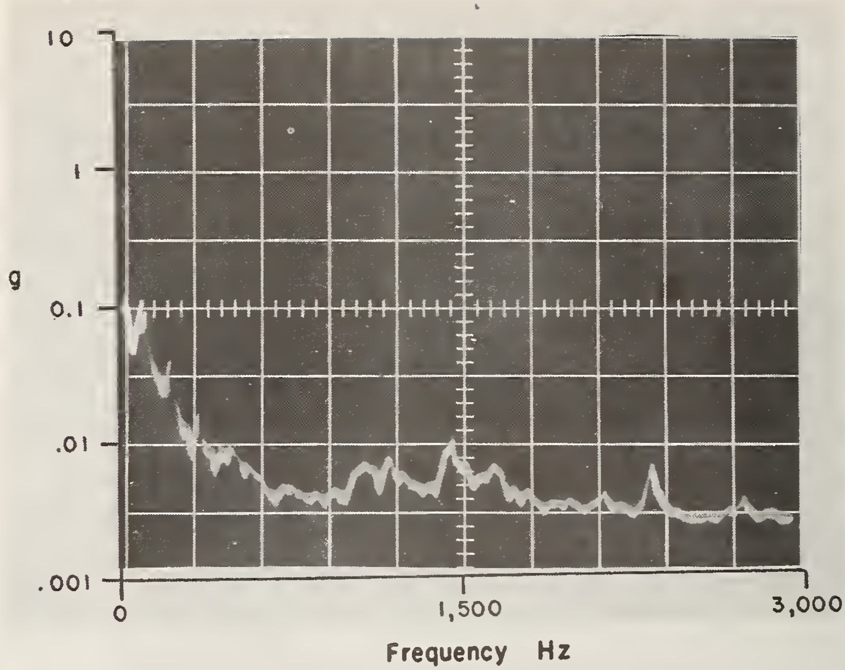


Figure 188. Vibrational Disturbances from 10' Resulting from Fence Lifting and Man Crawling Under; Test F4

Figure 189. Climb Over Top of Fence; Test F4

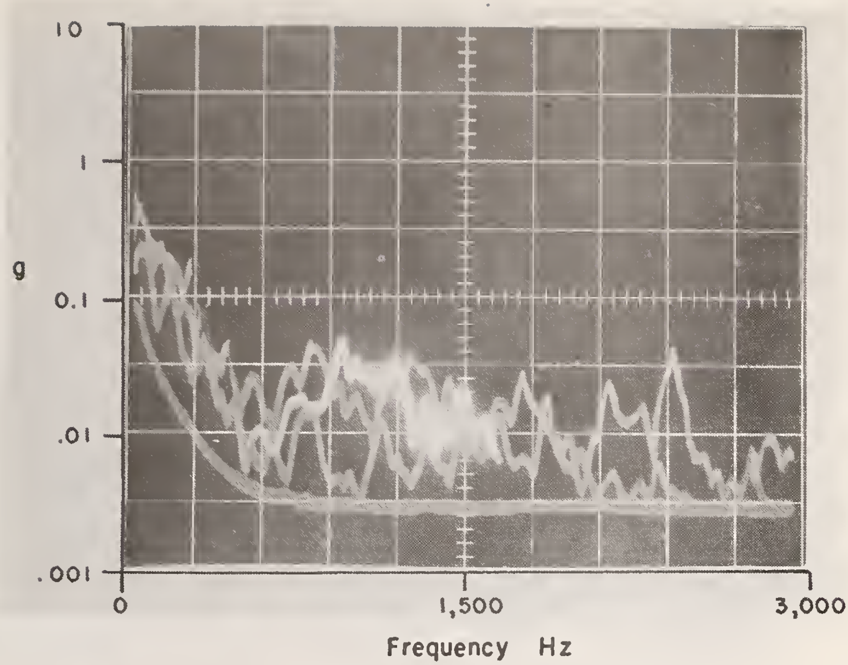


Figure 190. Vibrational Disturbances Resulting from Bolt Cutter Attacks; Test F4

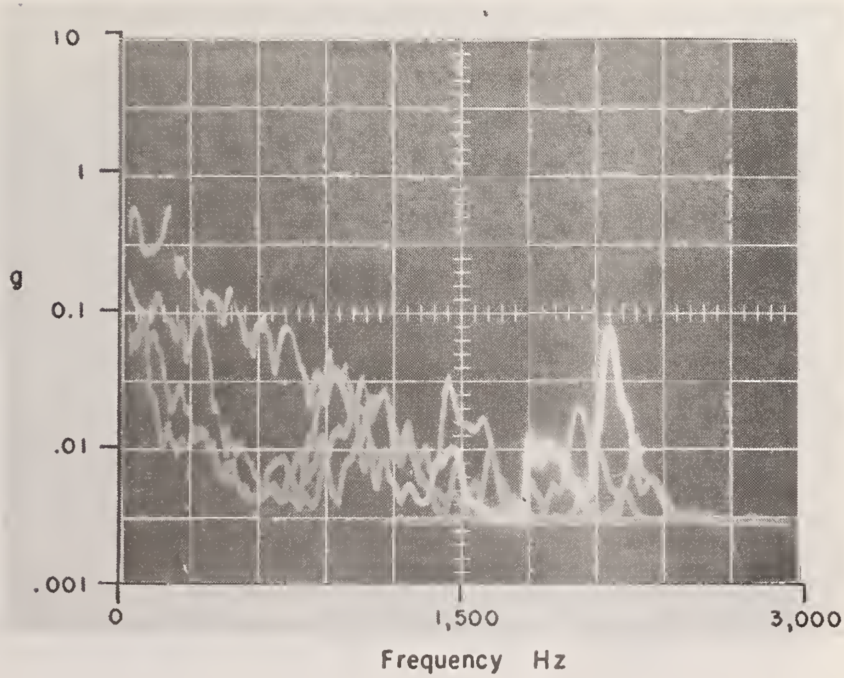


Figure 191. Vibrational Disturbances Resulting from Vise Grip Cutter Attacks; Test F4

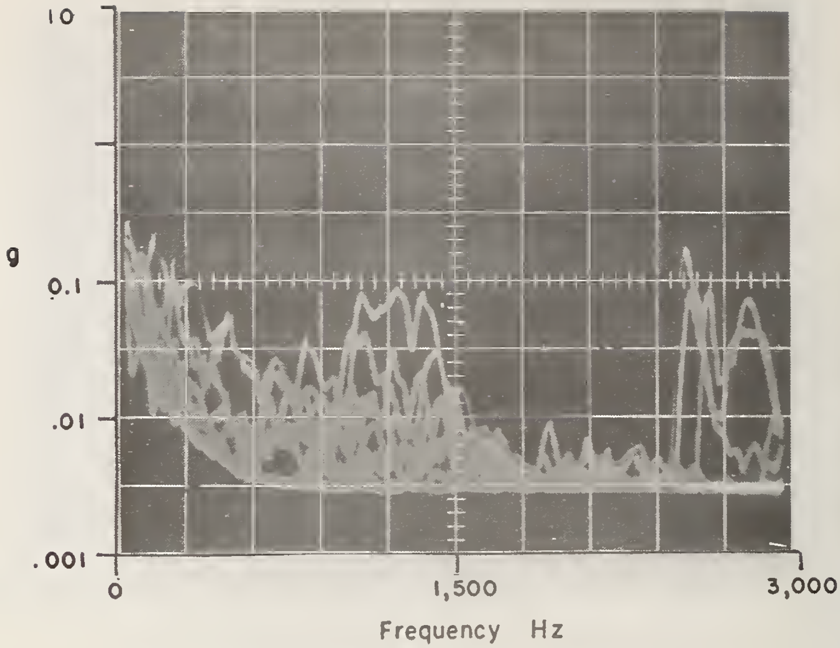


Figure 192. Vibrational Disturbances Resulting from Linesman's Pliers Attacks; Test F4

Figure 193. Metric Fence Pole Broken Off by Two-man Attack; Test F4

Figure 194. Details, Metric Fabric Attachment to Gate Frame; Test F4

Figure 195. Pulling Metal Fabric Away from Frame; Test F4

7.2.4 F4 This section of fabric was made from 2.65 mm wires, vinyl-coated, 50 mm mesh.

With the 2" X 4" timber, the bottom of the fence was easily lifted a foot above ground, and this, together with a man crawing under, took 0.08 minute. Vibrational disturbances as observed at a distance of 10' are shown in figure 188.

Climbing over the top of the fence, figure 189, took only 0.07 minute, and, like F3, the fabric could be pulled away from the top tension wire making an opening to crawl over in only 0.12 minute.

Only 11 wires had to be cut on this mesh to make an opening of the required minimum size. Using the No. 14 bolt cutters, this took 0.40 minute; with the vise grip cutters, it took 0.47 minute; with the linesman's pliers, it took only 0.28 minute, and the 6" diagonal pliers could not cope with the wire size. Vibrational disturbances from the bolt cutters are shown in figure 190, from the vise grip cutters in figure 191, and the linesman's pliers in figure 192. All were observed with the transducer mounted 4' from the attack location.

Because the metric gauge poles were obviously less rigid than the heavy wall pipe used for fence sections F1 and F2, it was decided to see whether they could withstand a two-man attack. The tension wires were cut at an intermediate post as were the tie wires fastening the fabric to the post. Then two men pushed hard and the pole broke just above the surface of the concrete in which it was embedded. The result is shown in figure 193. The total time required was 0.71 minute.

The metric gate was constructed with the F4 fabric which was attached to the gate frame by rather light tie wires which can be seen in figure 194. These were cut in five places and the fabric was pulled away from the frame as shown in figure 195 producing a half-oval opening that measured 12" X 29" in 0.34 minute.

Figure 196. Timber Lift and Crawl Under; Test F5

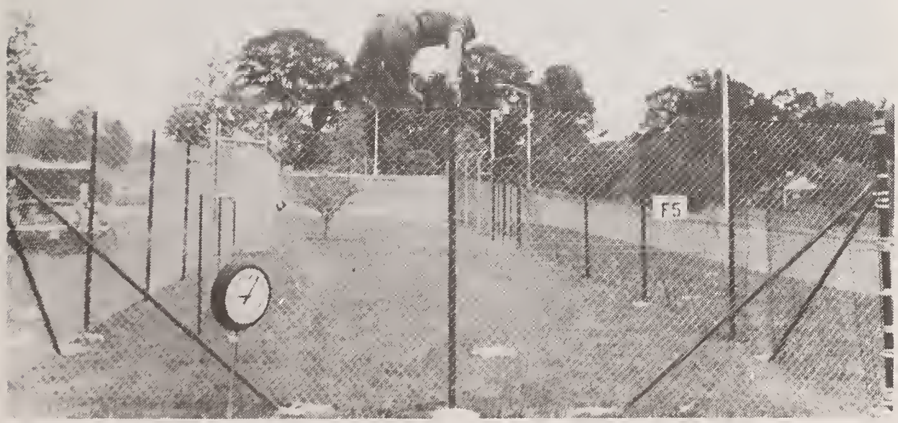


Figure 197. Climb Over Top; Test F5

7.2.5 F5 This section of fencing was constructed of 2.0 mm wire, 40 mm mesh, galvanized wire. The fabric had a rather soft, spongy feel when one pushed against it by hand and vibration disturbances were not observed above the ambient background from any of the cutting operations with the transducer located only 4' from the attack area.

The 2" X 4" timber lift and crawl under, figure 196, took 0.12 minute and a climb over the top took 0.05 minute, figure 197.

Thirteen mesh wires had to be cut to make the necessary opening size. These took 0.27 minute using the No. 14 bolt cutters, 0.25 minute using the vise grip cutters, 0.18 minute using the linesman's pliers and 0.29 minute using 4" diagonal pliers.

Cutting and pulling out a wire to unweave the fence fabric was done in a manner similar to that on F3. Because of increased friction, it was necessary to cut the wire in five places and pull it out in shorter sections. This attack required 1.08 minutes, but produced a complete separation in the fabric.

Finally, another intermediate pole was broken off using a repetition of the attack technique employed on F4. The time required was 0.57 minute and failure was at the same location as on the earlier test.

Figure 198. Lift Bottom Tension Wire and Crawl Through; Test F6

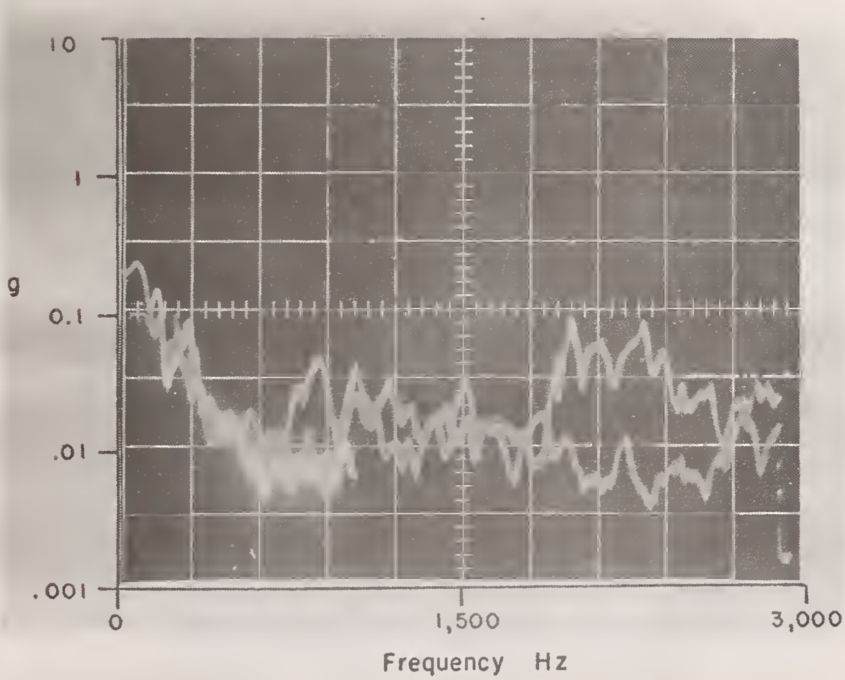


Figure 199. Vibrational Disturbances Produced by Lifting Wire and Crawling Through; Test F6

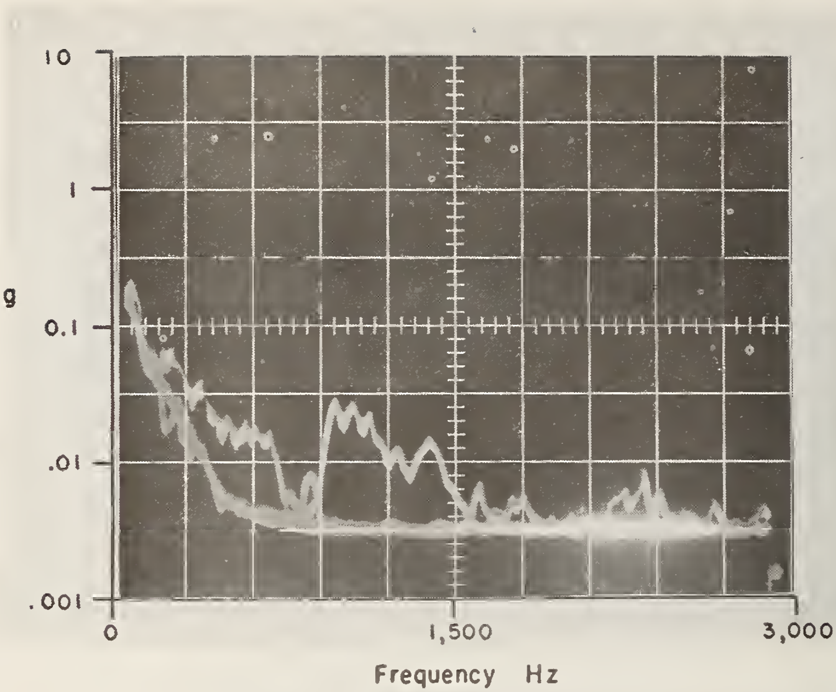


Figure 200. Vibrational Disturbances Produced by Bolt Cutter Attacks; Test F6

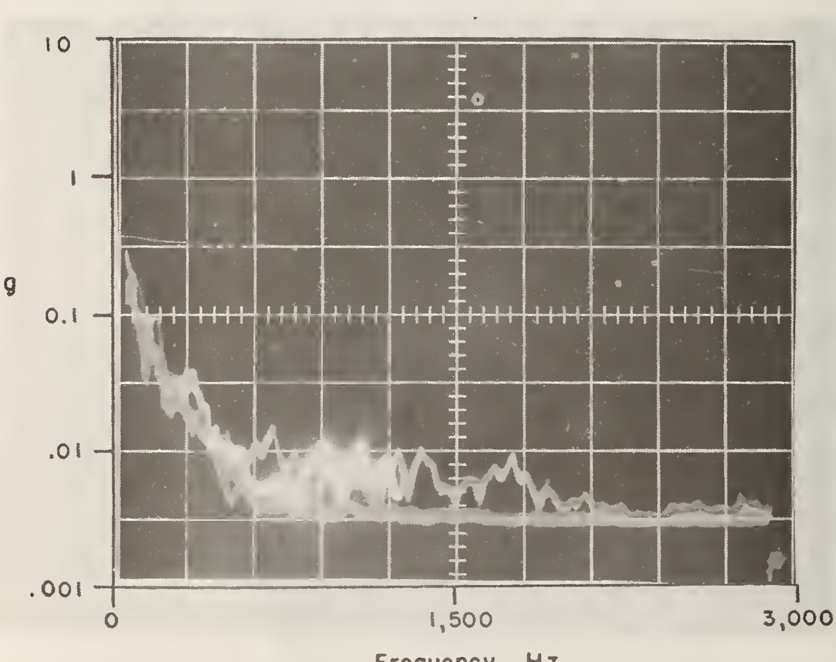


Figure 201. Vibrational Disturbances Produced by Vise Grip Cutter Attacks; Test F6

7.2.6 F6 The fabric in section F6 was 2.26 mm galvanized wire, 50 mm mesh, and the three coil pyramid of concertina wire was located just inside the middle of this section of fencing.

In order to clear the concertina wire, the location selected for the lift and crawl under attack was between the bottom of a diagonal corner bracing pole and the nearby intermediate pole. Despite this short span, it was still possible to lift the bottom tension wire and fabric enough for a man to crawl through as shown in figure 198. The time required was 0.19 minute and vibrational disturbances produced by the activity are shown in figure 199. Here, the transducer was at a distance of approximately 14'.

Climbing over the fence required 0.04 minute.

Cutting the fence to make a man-passable opening required cutting 12 wires. This took 0.20 minute using the No. 14 bolt cutters and, as observed at a distance of 12', the vibrational disturbances were as shown in figure 200. The vise grip cutters took 0.22 minute and produced slightly less disturbance, as shown in figure 201. Linesman's cutters took 0.17 minute and produced comparable disturbances as shown in figure 202. The 6" diagonal pliers took 0.22 minute and produced similar vibrational disturbances.

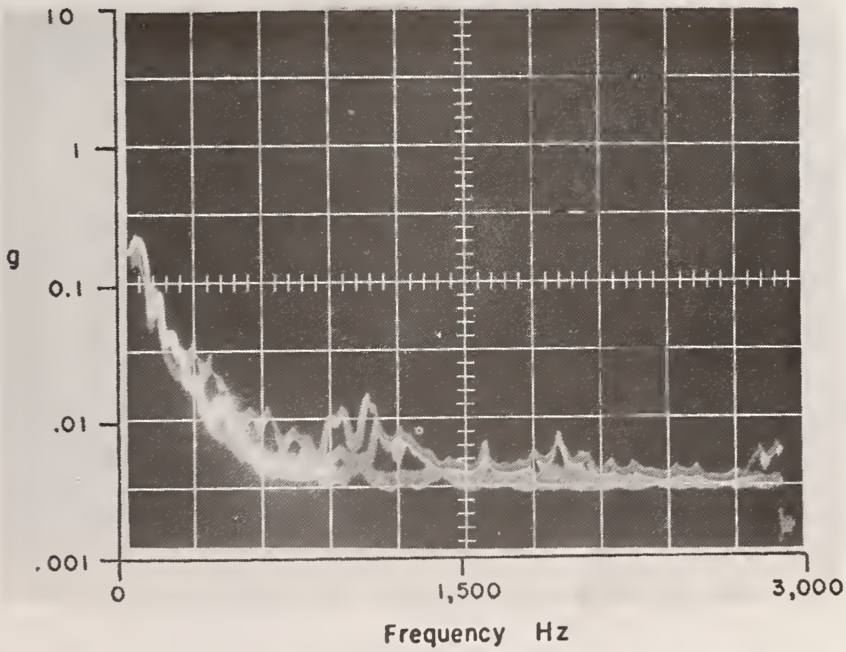


Figure 202. Vibrational Disturbances Produced by Linesman's Cutters Attacks; Test F6

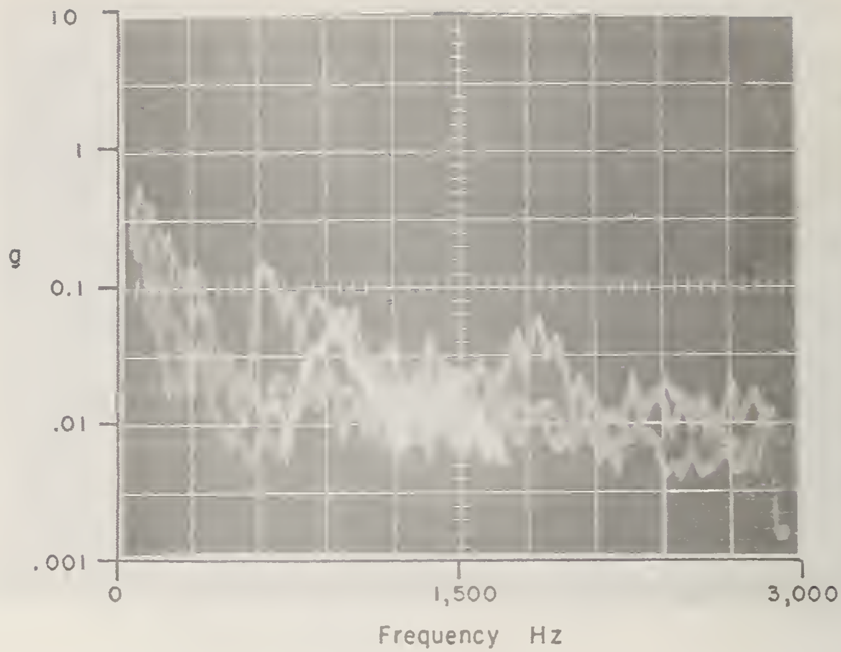


Figure 203. Multiple Sweep Trace of Vibrational Disturbances Produced by Wire Cutting; Test F6

Figure 204. Concertina Wire Spread Apart, Hooked to Other Strands Resulting in Crawl Through Space; Test F6

Figure 205. Climb to Throw Heavy Tarpaulin over Concertina Wire ; Test F6

Figure 206. On Top of Fence Getting Ready to Jump ; Test F6

Figure 207. Leap Clearing Concertina Wire Using Tarpaulin as Safety Factor; Test F6

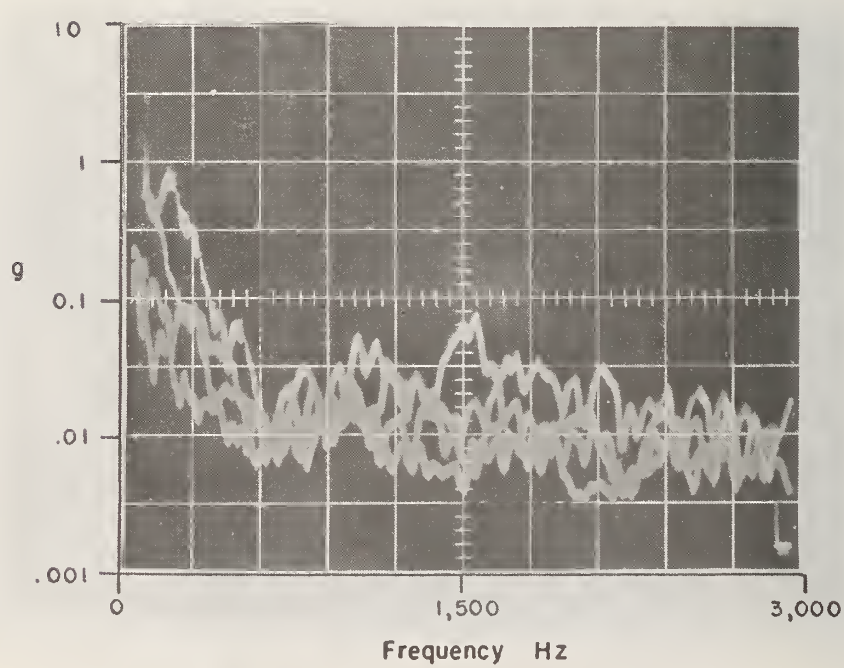


Figure 208. Vibrational Disturbances Produced During Climb with Transducer 4' Away; Test F6

Next, a penetration was made through the fence and through the concertina wire immediately behind the fence. First, fabric wires were cut, using linesman's pliers along a diagonal from the ground to a point about 42" high. This provided an opening large enough to manipulate the concertina wire. The three lower tension wires were also cut and the ends pulled aside. A multiple sweep trace of some of the vibrational disturbances produced by the wire cutting is shown in figure 203. Then the strands of concertina wire were spread apart and hooked to other strands so as to provide an open area through the bottom two coils which was large enough for a man to crawl through, as shown in figure 204. The hooks which were used were made from three-inch lengths of No. 9 gauge wire which had short reverse bends at each end. After the concertina wire had been hooked apart, two men crawled through the opening.

The total time required for this penetration was 4.14 minutes; however, neither operator had any prior experience with this particular technique so they had been specifically instructed to proceed cautiously. Although it was not done in this test, the hooks could have been removed and the concertina wire would have sprung back into its original position leaving no evidence that it had been traversed. Cutting the concertina wire would provide much more rapid passage but would leave clear evidence of the passage.

Figures 205, 206, and 207 demonstrate yet another technique which permits a two-man team to get one man inside the fence and concertina wire in 0.53 minute. One man provides support for the second who climbs up and throws a heavy folded tarpaulin across the top of the concertina wire. He then climbs to the top of the fence and leaps across the concertina. In this instance, the tarpaulin simply provided a safety factor as the leap cleared the concertina wire entirely. Figure 208 shows vibrational disturbances during the climbing with the transducer at a distance of about four feet.

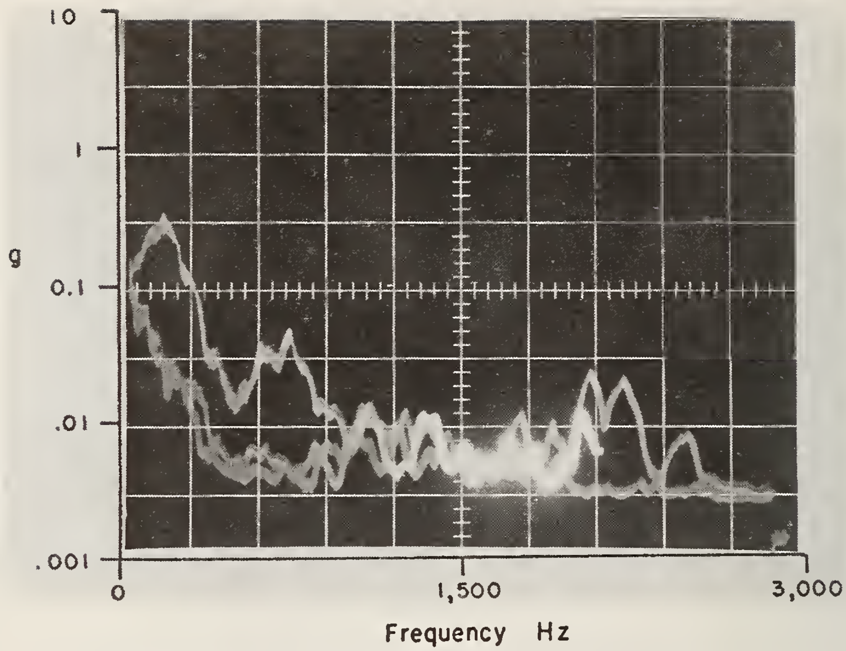


Figure 209. Vibrational Disturbances from Bolt Cutters on F7; Test F7

Figure 210. Cutting Metric Intermediate Post near Ground with Abrasive Wheel Saw; Test F7

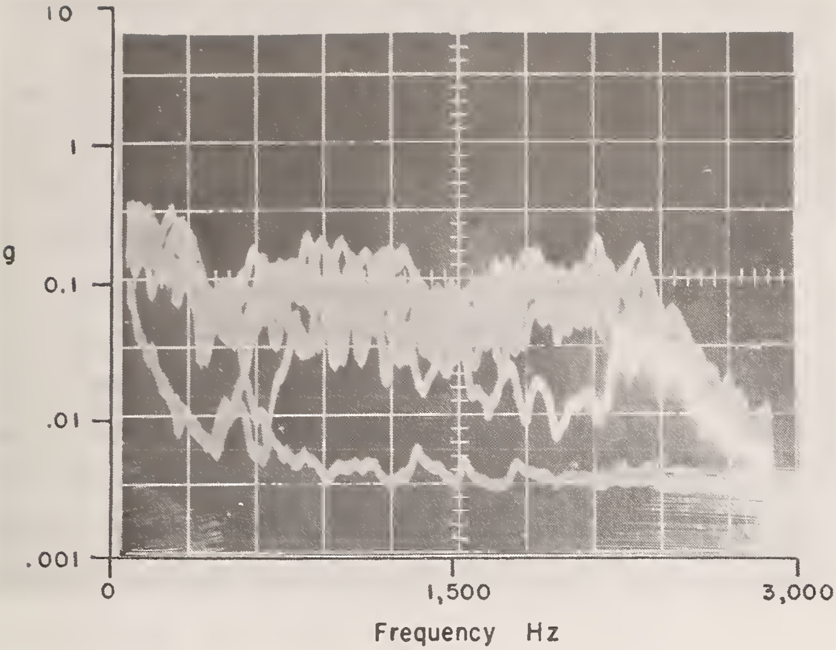


Figure 211. Vibrational Disturbances Produced by Abrasive Wheel Saw Attacks; Test F7

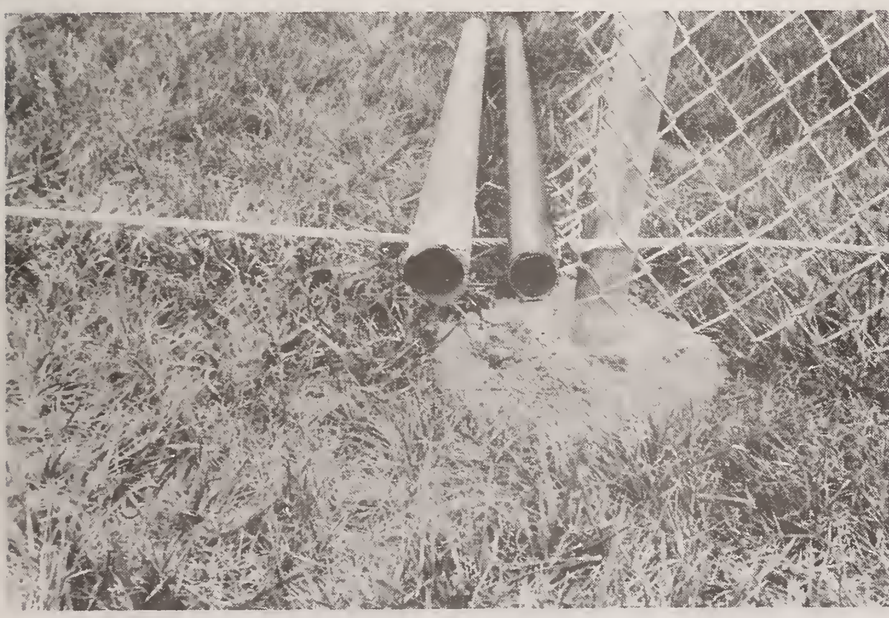


Figure 212. Comparison of U.S. and Metric Posts; Test F7

7.2.7 F7 This section of fence was constructed of fabric made of 2.65 mm galvanized wire with 60 mm mesh.

The lift and crawl test was not performed on this section because the tension wires had been cut in the adjacent section, F6.

Cutting a man-passable opening required severing 12 wires on this mesh. The vibration transducer was located approximately 8' from the attack point and disturbances produced by the 0.20 minute work with the No. 14 bolt cutters are shown in figure 209. The vise grip cutters took 0.19 minute, the lineman's pliers 0.20 minute, and the 6" diagonal pliers 0.14 minute. The vibrational disturbances which they produced were not significantly different than those shown for the bolt cutters.

The gasoline-powered abrasive wheel saw was used to cut off one of the metric intermediate posts near the ground, as shown in figure 210. This took 0.16 minute and produced vibrational disturbances, as shown in figure 211, with the transducer at a distance of 10' from the post. Figure 212 shows the comparative cross sections of the two types of intermediate fence posts used.

The abrasive wheel saw was also used to cut the full height of the fabric, as shown in figure 213. This required 0.11 minutes.

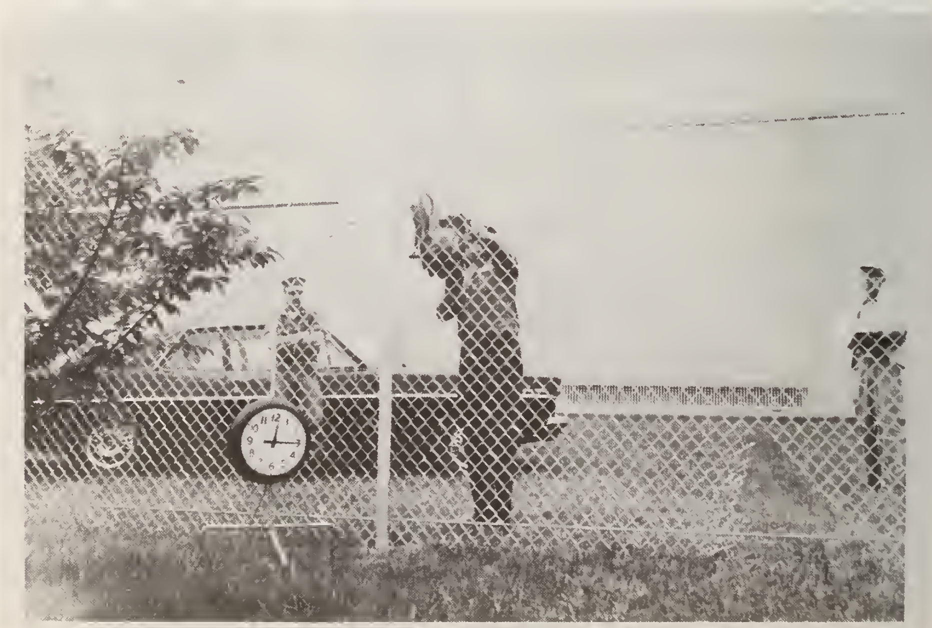


Figure 213. Cutting Full Height of Fabric with Abrasive Wheel Saw; Test F7

7.3 Discussion of Fence Test Results

The test results indicate that climbing over an unelectrified fence is probably the most effective method of penetration by a single man, and the same technique, or lifting up and crawling under the fence can be used by a two- or more-man team. The lift and crawl penetration permits the intruders to maintain a lower profile and reduces the chance of visible detection. Both methods leave little or no residual evidence that a penetration has occurred.

Penetration can be made quickly by a single intruder by cutting from 11 to 14 wires using a variety of tools, but this leaves an opening that is obvious in even a cursory inspection.

Table 4 summarizes the times in minutes observed on the various fence types for these modes of attack.

Table 4. Summary of Selected Penetration Times

Attack	F1	F2	F3	F4	F5	F6	F7
1. Lift and crawl under	0.10	0.14	0.12	.08	0.12	0.19	--
2. Climb, with tarp	0.15	--	--	--	--	--	--
with gloves	.06,.08	--	0.07	0.07	0.05	.04	--
3. Cut with:							
bolt cutters	0.32	0.27	0.32	0.40	0.27	0.20	0.20
fence tool	0.76	--	--	--	--	--	--
vise grips	No	0.79	0.39	0.47	0.25	0.22	0.19
linesman's pliers	No	0.39	0.33	0.28	0.18	0.17	0.20
6" diagonal pliers	No	0.59	0.21	No	--	0.22	0.14
4" diagonal pliers	No	--	--	--	0.29	--	--
abrasive wheel saw	.17,.26	0.44	--	--	--	--	.13,.11

In the table, a "No" indicates that the tool could not be used; a "--" indicates that test was not made.

In the lift and crawl under tests, the time variations do not appear to be strongly influenced by fence type. The span length over which the tension wire or tension messenger may be stretched is probably a more significant factor and was certainly responsible for the high value observed for F6.

In the climb over tests, the 0.06 and 0.08 minute climbs were made as the last two climbs in the series. There is some reason to believe that the sequentially decreasing times for F3 through F6 reflect improvements gained through experience. If this is true, then the presence of the barbed wire outrigger adds a few hundredths of a minute to the climbing resistance.

Small, No. 14 bolt cutters or a combination fencing tool are adequate to handle No. 9 gauge wire or smaller. Eight inch linesman's pliers are adequate for No. 11 gauge wire and are a little faster for the smaller gauges.

7.4 Conclusions

The test results indicate that the deterrent influence of unelectrified fencing of the types tested is largely psychological rather than physical. Thus, it would appear appropriate to select materials on the basis of avoiding the outward appearance of flimsiness and at the same time having enough real strength and durability to promise an adequate service life.

Meshes of the size used in F3, F5 and F6 have the visible appearance of flimsiness which should detract from their psychological deterrent value. F2 and F4 give the visual impression that they are more sturdy than they are in fact because the vinyl coating adds considerably more thickness to the wire than galvanizing. Another advantage to the green vinyl coating is the improved visibility which it provides by eliminating the glare and reflection which galvanized mesh produces under some lighting conditions.

Outriggers carrying barbed wire are considered quite cost effective. Their incremental cost per lineal foot is relatively small but they make a fence appear much more formidable. The outward sloping configuration is preferred.

The thin-walled, vinyl-coated tubing used in the metric fence posts gives a visual appearance of strength, but this is immediately dispelled if the post is shaken near the top. The standard pipe sizes used in the construction of F1 and F2 are probably a better choice purely on the grounds of better service life expectancy.

In summary, it is believed that an unelectrified fence can be penetrated so quickly by such a variety of means that the material selection will be most cost effective if based on service life considerations and an outward appearance of integrity. Vinyl-coated wire of 2.65 mm (No. 11 gauge) or larger and galvanzed wire of No. 9 gauge or larger creates this appearance in a mesh fabric. Mesh size in the ranges tested does not greatly influence the number of wires which have to be cut to make a minimum-sized, man-passable opening; however, mesh sizes greater than about 50 mm or two inches begin to look more open and should probably be avoided on this basis.

APPENDIX

During the course of this and three prior barrier penetration test series, sufficient data has been collected to permit certain general comments to be expressed regarding the capabilities and limitations of some of the tools which have been used and the observed range of their performance in selected materials.

The sledgehammer is the most important single tool in forcible barrier penetration. It is used alone or as an adjunct to other tooling in attacks on a great majority of materials. In fact, when the detailed structural composition of a barrier is unknown, it is usually worthwhile to initiate the attack for a minute or so with a sledgehammer. In the frequent cases where major damage results from the first minute of sledgehammering, continuation of that attack will usually result in a faster penetration than could be made using other tooling. The most effective size sledgehammer appears to be in the 6- to 12-pound range with the 10-pound size being preferred by most operators in good physical condition and weighing in the vicinity of 200 pounds. A smaller operator may be more effective with the 6- or 8-pound sledgehammer. The most effective situation occurs when the product of the mass of the hammer and its velocity squared is maximized. Most operators do not appear to be able to accelerate a 16- or 20-pound hammer to velocities high enough to make a major difference in the MV^2 product. Such increase as may be attained is offset by increased operator fatigue causing more rest requirements and a slower stroke rate. In sustained, multi-operator attacks using a 16-pound sledge, an average time of 1.68 seconds per blow has been observed compared to 1.58 seconds per blow for a 10-pound sledgehammer. For attacks involving only a short period of effort, times as short as 1.2 seconds per blow have been observed using the 10-pound hammer. For attacks which require working times on the order of 10 to 15 minutes, fresh operators will usually require about 90 seconds rest for each 30-second stint of hammering and four operators can usually maintain an excellent ratio of working to elapsed time. For attacks of longer duration, five or more operators may have to be employed to maintain this ratio.

Other useful impact tools are the cutting maul and the bar. The cutting maul is simply a sledgehammer with one side of the head formed into a wedge shape with a cutting edge. The bar is generally pointed at one end and equipped with a weighted wedge-shaped cutting edge at the other end. It is very useful in working in deeper openings which are not readily accessible to the sledgehammer. The 26-pound size appears to be a good selection and can be used at a speed of about 1.4 seconds per blow.

At the low end of the utility spectrum for impactive tools is the battering ram, at least in the 50-pound size commonly sold to fire and rescue units and designed for two-man, handheld operation. The transverse steel bar handles transmit intense impact shocks back to the hands of the operators when it is used against materials such as concrete, and it is less effective than a sledgehammer when used against even relatively fragile materials such as hollow concrete blocks.

The abrasive wheel saw can be used to cut virtually any of the materials likely to be encountered in structural barriers including concrete, masonry, steel, wood and plastic. Its depth of cut is limited by wheel size and is normally in the range of 2 to 5 inches. Cutting rates in concrete are on the order of 7 to 14 seconds per lineal inch for a 3-inch depth of cut. Because of the depth of cut limitations, it is usually most effective against relatively thin sections, particularly when these involve several different types of laminated materials such as, for example, a wood, steel, wood sandwich. It is very fast and effective against discontinuous metal materials of modest gauge, such as expanded metal, chain link fencing,or ferro-cement reinforcing wires, provided these are accessible to the working edge of the wheel. Where access is limited, or where continuous and thicker metals are encountered, one of the several types of flame cutting tools will usually be faster.

The rotohammer is indispensable, along with the sledgehammer and suitable punches, for making rapid, explosive free penetrations in reinforced concrete. This is accomplished by drilling a suitable pattern of holes partially through the concrete and spalling off the

interior using punches driven by the sledgehammer. This technique exploits the lower tensile strength of concrete as compared to its compressive strength. After one or more iterations of this process using successively shallower holes, the thickness of the barrier is reduced to the point that a small central area can be broken completely through with the sledgehammer.Then, a tapered punch driven into each of the peripheral holes in turn will spall material into this central breakthrough area and enlarge the opening. The fastest penetration results from a judicious choice of hole pattern, including size of holes and depth(s),so as to minimize the total time required for both drilling and spalling. The optimum pattern depends somewhat upon the characteristics of the concrete. It is difficult to spall out the bottom of a hole in fibrous concrete having a remaining thickness greater than about 2 or 2-1/2 inches. Ordinary concrete, with its lower tensile strength, can be spalled when the thickness is on the order of an inch greater. An empirical rule-of-thumb is to strive for a hole depth such that the residual thickness can be spalled out with an average of about 10 to 15 blows from the sledgehammer. If the bottom spalls out of the holes after only two or three blows, it is an indication that they are too deep and that more material could have been spalled out using a shallower hole. If an average of more than about 20 blows are required, the holes should probably be drilled a little deeper. Drilling rates in concrete are a function of drill size and material. In a given material, the drilling rate has been observed to be inversely proportional to the volume of material removed for drill sizes of one inch or less in diameter. Thus, it only takes about 56 percent as much time to drill a 3/4-inch hole as it does for a one-inch hole. Drilling times for one-inch holes have been observed over the range from 3.5 to 10.7 seconds per inch of depth depending upon the type of concrete. Lightweight concretes are at the lower end of the range, typically 3.5 to 5 seconds per inch. Regular concretes span the range from about 6 to over 10 seconds per inch. Usually the specimens in the 6-second region have been mixed with small size aggregate, 3/8- to 3/4-inch, and those at the upper end have large and very hard aggregate. The fibrous concretes which

have been tested employed 3/8-inch or less aggregate but showed drilling times of about 7 seconds per inch.

Using one-inch diameter holes and punches to make a penetration, the punches are seldom bent during the spalling operation, but an excessive amount of time is required for drilling. Faster penetrations can be made, but with a high punch mortality rate, using a 3/4-inch hole size. This does not add significantly to the logistics problem since punches are usually driven through the hole when the spall occurs and would not be recoverable after a single use until the penetration was completed.

The burning bar can be used to melt through concrete, but, since it does not afford a ready means of ascertaining hole depth, it is not easily substituted for the rotohammer in a drill and spall type of attack. Melting rates appear to be fairly well clustered in the range of about 5 to 8 seconds per inch and do not seem to be affected much by the type of concrete. There is fairly constant bar consumption in concrete at rates of about 1.0 to 1.25 seconds per inch using oxygen pressures of 160 to 200 p.s.i.. The burning bar is most useful in cutting steel. Typical average cutting times per lineal inch are 2.3 seconds for 1/4-inch thickness, 1.3 seconds for 1/8-inch thickness, and 2.28 seconds for 3/16-inch thick expanded steel. Here operation is at lower oxygen pressure, typically 75 to 100 p.s.i. and bar consumption is on the order of 2 seconds per inch.

Three other types of cutting torches appear to be quite comparable in cutting times as measured on 1/4-inch thick mild steel plate. These are the oxygen acetylene torch with No. 5 tip, the oxygen-fed electric arc, and the portable rocket cutting torch. All showed times of between 12 and 13 seconds per lineal inch.

Hand-operated cutting tools ranging in size from 3/8-inch bolt cutters down to 4-inch diagonal cutters can be operated at an average time of from 3.0 to 0.70 seconds per cut. The smaller tools designed for single-handed operation were generally operated in the range of 1.0 to 1.5 seconds per cut. Not unexpectedly, the fastest operation occurs when using the smallest tool which can comfortably make the necessary cut. For cutting steel fence fabric wire of No. 11 gauge or smaller, 8-inch linesman's pliers are most effective. For No. 9 gauge, the small No. 14 bolt cutters are preferable. These are quite effective on rods up to about 1/4-inch in diameter. For larger rod sizes, correspondingly larger sizes of bolt cutters will be more effective.

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SI Conversion Units

In view of the present accepted practice in this country for building technology, common US units of measurement have been used throughout this paper. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to US units used in this paper.

Length

1 in = 0.0254 meter (exactly)

1 ft = 0.3048 meter (exactly)

Force

1 lb (lbf) = 4.448 Newton (N)

1 kip = 4448 Newton

Pressure

1 psi = 6895 N/m^2

1 ksi = 6.895×10^6 N/m^2

Mass

1 lb = 0.453 592 37 kilogram (kg)

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Sixteen structural barrier panels were tested to determine their resistance to forcible penetration through the use of readily available tooling. Thirteen of these represented experimental techniques to reinforce an existing structural barrier of low penetration resistance; the other three were designs which would be most appropriate to consider as replacement barriers. Minimum man-passable sized openings were made in the barriers in working times which averaged 7.85 minutes and ranged from 1.52 to 25.56 minutes. One of the replacement and two of the reinforcing designs showed superior cost-effectiveness.

Seven woven, wire-mesh security fence specimens were also tested for their intrusion deterrence capability. The test results indicate that the deterrent influence of unelectrified fences of the type tested is largely psychological rather than physical. All of the specimens could be penetrated in 0.14 minutes or less.

Samples of the acoustical and vibrational data produced during the penetration tests add to the growing body of data which are expected to be useful in the design and selection of electronic intrusion alarm equipments.

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